Effects of Biliteracies on Bilingual Cognitive Functions

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Abstract

Although previous research has examined the effects of bilingualism on cognitive functions, specific biliteracy effects have not been investigated. This thesis looks at the effects of script on three major components of cognitive functions: executive control, mental rotation and hemispheric variance in distinguishing morphological markers. The research is composed of three studies, each focusing on a different aspect of cognitive functions.

Study I compare's English monolinguals, Arabic monolinguals, English/Maltese bilinguals and English/Arabic bilinguals. The groups are tested using several executive control tasks (TEA and AX-CPT), concentrating on the fact that, like English, Maltese uses the Latin script, while Arabic uses its own. Maltese has the advantage of sharing a wide range of linguistic characteristics with Arabic, however is the only Semitic language to be written in the Latin script. Results revealed no significant effects of biliteracy on the executive control tasks related to inhibition and switching.

In Study II, mental rotation is examined using three Corsi Block Tapping task; Forwards, Backwards and Rotated. The tasks were utilised in order to compare the English, Arabic, and Maltese groups on mental rotation. The results found that both Arabic speaking groups outperformed on the Rotated Corsi, while the English monolinguals and English/Maltese bilinguals did not. This showed that while script does make a difference for mental rotation, it is an aspect of linguistic diversity, specifically the Arabic script, and not biliteracy. Further comparisons were done on Chinese monolinguals and bilinguals and led to the same conclusion, that the effects found on the mental rotation task are specific to the Arabic script. Further research on late Arabic learners revealed that the mental rotation effect is found after only one year of Arabic study.

Study III utilised a visual and an auditory lexical decision task in order to investigate whether there are differences in hemispheric usage between the groups when making linguistic judgments. Previous research had suggested that Semitic languages, employ the use of both hemispheres of the brain in distinguishing morphological markers, whereas English readers rely on the left hemisphere (Ibrahim, Israeli, & Eviatar, 2007). The script differences between Maltese and Arabic helped determine whether the previous results were linked to the directionality of the script or the morphemes themselves. Results reiterated that both Semitic languages, Maltese and Arabic, showed no hemispheric preference in Maltese and Arabic respectively, however both groups and the English monolinguals showed a left hemispheric preference in English.

The three studies report unique finding on an aspect of bilingualism that has not been examined, biliteracy. While the results did not show biliteracy effects on cognitive functions, linguistic diversity was shown to have an effect on both mental rotation and hemispheric variance in distinguishing morphological markers.

Lay Summary

Studies have shown that speaking two or more languages may have a positive effect on non-language areas of the brain. The main effects include bilinguals showing better results on tasks related to executive control; which are skills needed to successfully select and monitor behaviour in order to achieve a specific goal.

The thesis compares bilinguals who use the same scripts in both languages with bilinguals who know and consistently use languages with two different writing systems. Our bilingual groups main comparison are bilinguals who consistently speak English and either Maltese or Arabic. Similar to English, Maltese uses the Latin script, while Arabic uses its own. Maltese has the added advantage of sharing a wide range of vocabulary and grammar with Arabic. Therefore comparing the groups will help show us whether bilinguals who use languages with two writing systems show different results on tasks related to executive control, as opposed to bilinguals who only know one writing system.

Our research examines this point from three different angles. Study I examines the differences in performance between the English/Maltese bilinguals and the English/Arabic bilinguals on tasks related to executive control such as; inhibition and switching. The second study compares their performance focusing on their ability to rotate objects mentally. Study III focuses on the differences in processing morphological markers, such as past tense 'ed', between the groups in all three languages.

The comparison of the groups on these three aspects showed that while no effects were found for those who knew more than one script, specific script effects were found. Different languages therefore show varying effects on executive control, mental rotation and in processing morphological markers.

Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or processional qualification except as specified.

The data presented in Chapter 3: Experiment 2 of this thesis was obtained in an experiment carried out by Helen XIA Lihua in China. I played a major role in the preparation of the experiment, and the data analysis and interpretation are entirely by own work.

Reham Al Rassi
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Introduction

More than 3.5 billion people are currently bilingual or multilingual (Grosjean, 2010). Historically, however, educators have discouraged second language learning, fearing that the high cognitive demands may lead to delays in general cognitive development and lower IQs (Hakuta & Diaz, 1985; Saer, 1923). These attitudes have shifted in recent years as research has found that bilinguals and multilinguals perform similarly, or even outperform, their monolingual peers in cognitive function tasks (Antoniou et al. 2016; Kroll & Bialystok, 2013).

Bilingualism's effects on cognitive functions provides the backdrop for this thesis. Although previous research has examined the effects of bilingualism on cognitive functions, specific biliteracy effects have not been investigated. While the term 'biliterate' has been used to define a bilingual's knowledge of more than one language, regardless of script, in this research, biliteracy is used specifically to refer to a bilingual's knowledge of two different scripts. While other research has investigated differences between bilinguals, such as age of second language acquisition, proficiency, and code switching (Prior & Gollan, 2011; Ooi, Goh, Sorace, & Bak, 2018), in this thesis we examine whether individual aspects of language, specifically writing scripts, have an effect on cognitive functions. Script is perhaps the most easily distinguishable characteristic of a language, with more than 3000 languages having an established writing system (Simons & Fennig, 2018). In order to examine specific effects of script, the main languages analysed in this thesis are English, Maltese and Arabic. These three languages allow a unique examination of the effects of script, since while Maltese and Arabic both share common language aspects such as morphology, grammar, and vocabulary, they do not share the Arabic writing system, whereas Maltese, like English, utilises the Latin script. Maltese/English bilinguals, therefore, while sharing multiple language aspects with Arabic/English bilinguals, differ on script. A detailed description of the three languages and their characteristics can be found in Chapter 1 (1.1).

The main objective of this thesis is therefore to investigate bilinguals, specifically Maltese/English and Arabic/English bilinguals, in order to distinguish the effects of script on three major components of cognitive functions: executive control, mental rotation and hemispheric variance in distinguishing morphological markers. The thesis is divided into five chapters, detailed below.

After a detailed background (Chapter 1), three experimental studies are conducted (Chapters 2, 3, 4), in order to answer the following main research questions:

1. What are the main effects of biliteracy on executive control in both lifelong and late bilinguals? (Study I)
2. Does script influence mental rotation independently of bilingualism? (Study II)
3. Is the hemispheric variance in distinguishing morphological markers found in previous research on Semitic languages influenced by script? (Study III)

Chapter 1 contains four sections. The first describes the differences between English, Maltese and Arabic, and why this language combination may help control for script effects on cognitive function tasks. The second section explains the relationship between bilingualism and the cognitive functions related to executive control (study I) and mental rotation (study II). Since our results lead us to a discussion of linguistic distance and diversity of linguistic background, this forms the focus of the third section of this chapter. The final section provides background for study III by examining previous research on distinguishing morphological markers.

The first study 'Effects of Biliteracies on the Executive Control of Lifelong Bilinguals and Language Learners', contains two experiments and is detailed in **Chapter 2**. Utilising two tasks designed to examine the relationship between biliteracies and executive control components, such as inhibition and switching, the first experiment focuses on these effects in lifelong bilinguals, and the second experiment in late language learners. The study (Study I) compares English monolinguals, Arabic monolinguals, Maltese/English bilinguals, and Arabic/English bilinguals in the first experiment, using two different tasks for executive control: AX-CPT and the TEA. Both tasks are explained in detail in the study and investigate executive control mechanisms popular in bilingual effects research; specifically, inhibition and switching. The second experiment tests English speakers learning a morphologically complex language, such as Arabic, during their university years. The same tasks are utilized as in the first experiment to investigate if biliteracy effects are present in late language learners.

In **Chapter 3**, Study II 'Effects of Arabic on Mental Rotation' contains three experiments and compares several groups on three versions of the Corsi block tapping task: a Forwards, Backwards and Rotated Version, focusing on the effects of biliteracy on mental rotation. The first experiment compares the same English, Maltese and Arabic groups as in the first study, to examine whether Arabic's right-to-left writing makes a difference to mental rotation when compared with the Latin's left-to-right. The second experiment utilises the same tasks but with the addition of three Chinese speaking groups: monolingual Chinese, low proficiency Chinese/ English bilinguals, and high proficiency Chinese/English bilinguals. The addition of Chinese attempts to differentiate whether writing directionality influences the outcomes of the Arabic speaking groups on the Corsi Rotated task, or if the results are due to another feature of Arabic script. The Chinese writing directionality can be either horizontal or vertical, and although Western influence has resulted in increased left-to-right writing; signs, historic scripts, and newspaper headlines, are still found written from right-to-left. The effect of the Chinese directionality when compared to the results found in the Arabic groups may help identify if the results are due specifically to script directionality. While the first two experiments centre on lifelong bilinguals, the third experiment examines speakers learning Arabic at a later stage in life, specifically for their university studies, in order to investigate whether later script acquisition is associated with any difference in the outcomes of the mental rotation tasks.

The final study 'Effects of Biliteracy on Hemispheric Variance', detailed in **Chapter 4**, is based on a study on Hebrew and Arabic speakers conducted by Eviatar and Ibrahim (2007). This study suggested that Semitic languages, such as Arabic and Hebrew, employ the use of both hemispheres of the brain in distinguishing morphological markers, whereas English speakers employ only the left hemisphere. In light of these findings, this research questioned whether biliteracy, and specifically script directionality, caused the dual hemispheric activation when distinguishing morphological markers in Arabic and Hebrew. The question rose due to the fact that both Arabic and Hebrew are Abjad writing systems and begin from right-to-left, as opposed to the left-to-right writing directionality of English. The results however could also be due to the complex morphology present in both Arabic and Hebrew. The comparison of the English, Maltese and Arabic groups would clarify this, since Maltese, while sharing Arabic's complex morphology, is written using the Latin script. Eviatar and Ibrahim (2007) used a visual Lexical Decision Task, with words and non-words appearing either on the right or left side of the screen, with participants' response time serving as the point of comparison. Study III of this thesis extends this by adding an auditory Lexical Decision Task so that participants could hear the words in the second task. The tasks were administered using English, Maltese and Arabic words. The bilingual groups completed both the English version of the task, in addition to the one in their respective language.

The chapters detailing the three studies (chapters 2, 3 and 4) include detailed introductions, methodologies, results, and discussions of the research. **Chapter 5** concludes with a general summary, as well as the implications and limitations of this research.

Chapter 1: Background

1.1 English, Maltese, and Arabic

In order to study the specific effects of script on cognitive functions, three languages were chosen: English, Maltese and Arabic, divided into four user groups: English monolinguals, Arabic monolinguals, Maltese/English bilinguals and Arabic/English bilinguals. It was not possible to add a Maltese monolingual group since, although Maltese is the official language of Malta, so is English, and therefore both languages are commonly used throughout Malta. As referenced in the introduction, both Maltese and Arabic share a wide range of characteristics; however the main distinction is their writing script. Maltese, like English, utilises the Latin script, whereas Arabic uses its own Arabic writing system.

English was chosen because of its universality, the ease of finding English speakers in Edinburgh and knowing that the majority of international bilinguals would most likely speak English as a second language. English belongs to the Indo-European language family and uses the Latin script. With over 145 scripts worldwide, the Latin script is the most widely used in the world, with almost 4.9 billion users (ScriptSource, n.d.). Most languages utilising the Latin script, including English and Maltese, use the standard 26 letter alphabet, although some variance does exist. Maltese, however, does not share an ancestral language with English and is therefore not an Indo-European language but is a part of the Semitic language family, a trait it shares with Arabic. Maltese is in fact the only Semitic language to utilise the Latin script for its writing.

Whereas English does not share an ancestral language with Maltese or Arabic, with thus fewer shared language characteristics, the common Semitic heritage of Maltese and Arabic means that they do share many characteristics. Forty percent of Maltese vocabulary is shared with Arabic (Brincat, 2005). Everyday speech and high frequency function words in particular, are similar. Numbers and days of the week, for example, are essentially the same in both languages; however more abstract words reveal Romance and Germanic influences on Maltese.

The Arabic script has been used to write the Arabic language since the 4th century and is the second most widely used script in the world (ScriptSource, n.d.). Interestingly, both the Latin and Arabic script are historically derived from the Phoenician writing system. The Greek alphabet, from which the Latin script is derived, is a direct descendant of the Phoenician writing system, and is sister to the Aramaic alphabet, which later led to the development of the Arabic script. The Phoenician alphabet perhaps more closely resembles the modern Latin alphabet than the Egyptian hieroglyphics from which it was derived, yet bears little to no resemblance to the modern Arabic script. Both Phoenician and Arabic, however, are written from right-to-left and are Abjad writing systems. In Abjad scripts, vowels, unlike consonants, are not represented with their own distinct letters, but as diacritical marks. Arabic script however is considered an ‘impure Abjad’ as the alphabet contains three long vowels (Daniels, 2013).

Arabic is the fifth most spoken language in the world, with more than 400 million speakers (Simons & Fennig, 2018). It is the official language of 22 countries and carries significant weight for the 1.8 billion Muslims worldwide as the official language of the Islamic text, the Quran. Many Muslims while not able to speak or understand Arabic fluently, can easily read the Arabic script due to their constant reading of the Quran. As stated previously, the Arabic script is written from right-to-left. Arabic letters are rarely used independently and words are instead composed of connected letters. 22 of the 29 letters of the Arabic language have up to four different shapes depending on where they occur in a word; initial, middle, final, and when following a non-connecting letter. For example, /gh/, is written as < غـ > in the initial position, as < ـغـ > in the middle position, as < ـغ > in the final position, and as < غ > on its own. Many Arabic consonants also carry dots and, unlike most languages, the dots are an integral mark of the letter. Some letters have an identical form and can only be distinguished by the placement or number of dots, such as the phonemes /b/ < ب >, /t/ < ت >, and /th/ < ث >. Of the 29 Arabic letters only three are vowels, since the majority of vowels occurring in words are represented by diacritical marks above, below, or within, the body of the word. Arabic text is made more complex and ambiguous by the practice of omitting the vowel diacritic marks in casual written remarks and texts. Research on the differences in processing between different orthographies found that the joining of the Arabic script may promote orthographic learning and that words with many consonant diacritics take considerably longer to read (Dai, Ibrahim & David, 2013). Further research has showed that the visual complexity of Arabic orthography creates extra difficulty in reading Arabic texts (Ibrahim, 2011).

Arabic and Maltese share a majority of grammar rules (Čéplö et al., 2016). Maltese grammar is derived from Siculo-Arabic and therefore both Maltese and Arabic share a large number of grammar characteristics, including the pluralisation of nouns and the conjugating of verbs by deconstructing the root, flexibility of word order, and inclusion of the definite article within the word. Whereas non-Arabic loan words in Maltese follow borrowed grammar rules. Word order for Arabic sentences is Verb-Subject-Object, unlike English's Subject-Verb-Object; however both word orders are acceptable and consistently used in both Maltese and Arabic. All verbs and most nouns follow a root system in Arabic, meaning the words are primarily three letter consonantal roots remodelled in order to form the lexicon (Berman, 1978). Among other specifications, nouns in Arabic occur in nominative, accusative and genitive cases, whereas verbs are marked for person (first, second or third). In addition, both nouns and verbs are marked according to number (singular, dual and plural) and gender (masculine and feminine). Non-concatenative patterns are taken into account in order to follow grammatical rules in both Arabic and Maltese. Since Arabic is a root-based system, non-concatenative morphology does not form words by sequentially arranging morphemes, but by deconstructing and modifying the word’s root (Haspelmath, 2002). Plural morphological markers in the three languages can be used: for example, English: book > books, Maltese: ktieb > kotba, Arabic: /kitæb/ كتاب > /kɔıtb/ كُتب. As can be seen from the example, the root words in both Maltese (ktb) and Arabic (كتب) are essentially three constants modified from within to become plural, whereas in English a plural ’s’ was added to the word ‘book’, as is done with the majority of English nouns. Almost all Arabic words can therefore be simplified to their root and any pluralisation of nouns, and verb conjugating, must modify the root by adding letters within the three root constants.

There are three pertinent implications of Arabic’s linguistics for this thesis: firstly, comparisons between Maltese and Arabic may help control for specific script differences between groups; secondly, the Arabic writing system’s complexity may have unique cognitive effects (Chapter 3); and, thirdly, both Arabic and Maltese share a complex morphology (Chapter 4). Since Maltese and Arabic share a wide range of language characteristics, but differ in their script, comparing Maltese/English bilinguals and Arabic/English bilinguals on cognitive function tasks may indicate whether different scripts exert different effects on executive control (Chapter 2). As detailed above, the Arabic writing system’s inclusion of integral dots and diacritic markings, as well as several versions of each letter based on word position, creates a complexity not found in the majority of writing systems. How cognitive functions are affected by the intricacy of the Arabic writing script will be more closely explored in the second study concerning mental rotation (Chapter 3). The complexity of the Arabic and Maltese morphology, especially regarding morphological markers, has also been detailed above. Morphological markers in Semitic languages such as Arabic and Maltese are usually added by deconstructing the root, as opposed to simple prefixes or suffixes in English. In order to understand more fully the effects of the morphological markers on cognitive functions, in the third study we compare brain hemispheric differences regarding the task of distinguishing the markers in all three languages (Chapter 4).

Another unique aspect of Arabic is that speakers utilise a dialect of Arabic in everyday speech that differs from the Modern Standard Arabic used in texts, official settings and news broadcasts. The Arabic dialect is rarely seen in its written form; unless in informal text messages between friends and family, and Modern Standard Arabic is almost never spoken in everyday conversations. There are a multitude of Arabic dialects, and a few are to some extent mutually unintelligible, such as the Moroccan Arabic relying heavily on French loan words compared to Egyptian Arabic. All Arab speakers learn Modern Standard Arabic at school and utilise it on a daily basis. The diglossia in Arab communities, and the differences between Modern Standard Arabic and its dialects, have led to research showing them as being processed as different languages by Arabic speakers (Ibrahim, 2009). This research is taken into account when interpreting the results found in the studies contained in this thesis (chapters 2,3,4). The Arabic dialect used by the Arabic speakers in this thesis is the Gulf dialect, specifically the Najdi Arabic found in central Saudi Arabia.

1.2 The Relationship between Bilingualism and Executive Control

The first study utilizes tasks related to inhibition and switching, in order to examine the effects of biliteracy on executive control. The relationship between bilingualism and executive control has been the source of extensive debate in linguistic research. Successful sentence comprehension and production requires the use of several mechanisms of executive control, and since these mechanisms are employed to monitor conflicts and make selections among competing lexical representations, the addition of another language makes the process more onerous (Ye & Zhou, 2009). Further research suggests that this mental effort causes bilingual speakers to have equal or better ability with non-verbal executive control tasks than monolingual speakers. This perceived effect of bilingualism on a bilingual person's executive control has been attributed to the joint activation of both languages and the need to suppress one while using the other (Abutalebi & Green, 2008; Calabria, Hernández, Branzi & Costa, 2011; Kroll & Bialystok, 2013).

Executive control is defined as a general-purpose mechanism that controls and regulates cognitive functions; examples include working memory, inhibition and switching (Miyake & Friedman, 2012). Due to the broad definition of executive control, and their fluid nature and lack of specific borders, their assessment is difficult and the results of the tasks required to measure them have been debated (Paap & Greenberg, 2013). Nonetheless, many researchers agree that bilingualism effects can be found on the executive control processes related to inhibition and switching. Inhibition is defined as the deliberate suppression of dominant or reactive responses, and is usually generalised for bilinguals as a task-general inhibitory control advantage, or as the bilingual inhibitory control advantage (BICA) hypothesis, as expressed by Hilchey and Klein (2011). Switching is the ability to shift between mental tasks, by releasing inhibition and any possible negative priming effect present, which is a memory effect that negatively influences a response to a stimulus due to previous exposure to the same stimulus (Miyake & Friedman, 2012).

Research on the relationship between bilingualism and executive control has shown lifelong effects, since executive control appears to develop earlier in bilingual than in monolingual children (Bialystok, Craik & Luk, 2008; Carlson & Meltzoff, 2008). A study by Kovács and Mehler (2009) showed that bilingualism influences inhibition before speech is even produced. Using eye tracking technology to study 7-month old infants they demonstrated that infants being raised in a bilingual household had better inhibition results than monolingual infants. Further research examining adult bilinguals also revealed the bilingual groups outperforming their monolingual peers on executive control tasks (Morales, Gómez-Ariza & Bajo, 2013; Vega-Mendoza, West, Sorace & Bak, 2015). Prior and MacWhinney (2009) tested monolingual and bilingual university students in a task-switching paradigm and found that the bilinguals had smaller switching costs than monolinguals, leading them to conclude that the lifelong experience of switching between languages may lead to increased efficiency in the ability to shift between mental sets. Another study found that adult bilinguals had a shorter response time than monolingual adults when tested on their ability to switch between two types of categories: age and gender when applied to the categorisation of facial images (Marzecová et al., 2013). These lifelong results have ultimately led researchers to conclude that, among older participants, bilingualism delays the decline of executive control abilities due to aging (Alladi et al., 2013; Gold, Kim, Johnson, Kryscio & Smith, 2013). These bilingual effects have been demonstrated successfully in several studies, although other studies have failed to replicate them (Hernández, Martin, Barcelo & Costa, 2013; Paap & Greenberg, 2013).

Recent work has moved beyond the generalisation of bilingualism regarding executive control tasks to examine individual differences in bilingual usage and development, since studies have found that the bilingual effect may be both task and sample specific (Ross & Melinger, 2017). For example, the prevalence of language-switching in some communities has been shown to influence inhibitory control (Prior & Gollan, 2011). Further research has showed that the interactional context of a bilingual's switching produces different results in attentional tasks (Ooi, Goh, Sorace

& Bak, 2018), thereby reaffirming that bilingualism is too general and that studies should control for the type of bilingualism, and bilinguals. In this context, the study in Chapter 2 specifies biliteracy, and the learning of an additional script, as a possible variable regarding a bilingual's executive control.

While cumulative evidence shows that bilingualism affects cognitive functions, the nature of the effect is highly uncertain. There are many variables that may influence bilingualism, specifically proficiency, age of acquisition and language usage. This has led to a large percentage of studies regarding bilinguals to focus on early, highly proficient bilinguals, with limited attention on bilinguals who learn the language after childhood (Hilchey & Klein, 2011; Pelham & Abrams, 2014; Tao et al., 2011). In studies I and II, we examine monolinguals, lifelong and late biliterate speakers. In the third study we only compare lifelong bilinguals with monolinguals. While monolinguals are rarely truly monolingual, since most schools currently provide language learning in their curriculum, language variables were measured using a language questionnaire (detailed in 2.2.2), and monolinguals were defined as those with no proficiency of other languages above 25%. We defined lifelong bilinguals as those who have learnt and consistently used both languages before the age of eight. Late language learners were defined as those who first began learning Arabic at university, with no knowledge of another language that used a script other than the Latin alphabet. This is due to the difficulty in finding Arabic language learners and it was very rare to encounter a native English speaker learning Arabic as their first foreign language. Since this research attempts to examine script specifically, language learners who had knowledge of scripts other than Latin were excluded, but not those who knew other languages. We therefore made no differentiation between bilinguals and multilinguals, as the majority of our participants are multilingual. Several several studies have previously shown no significant difference between the two on tasks related to executive control (Alladi et al., 2013; Vega-Mendoza et al., 2013).

Another main issue is immigration bias. Arguments state that comparing bilinguals of immigrant backgrounds with monolinguals with non-immigrant backgrounds constitutes a confounding variable, since immigrants may exhibit higher intelligence. This may be shown by their (or their parents') resourcefulness and strength in relocating and adjusting to a new country. We attempt to control for this by testing participants in the countries of their predominant language, as our early bilinguals are all either from a bilingual country (Malta) or have learnt English in their native country as English gains in universality (Saudi Arabia). We also compare our bilinguals to two monolingual groups, from the UK (English) and Saudi Arabia (Arabic). Socioeconomic status and education is also controlled with a detailed questionnaire.

Scientists have also debated task validity, specifically the fact that there are multiple variances and influences in respect to cognitive functions on a specific task that cannot be captured by one task. Discussions regarding executive control have examined whether tasks test working memory, inhibition or task switching individually, or utilise a combination of these cognitive functions (Abutalebi & Green, 2008; Bialystok & Viswanathan, 2009; Costa et al., 2009; Hilchey & Klein, 2011; Kroll & Bialystok, 2013; Ye & Zhou, 2009). In order to address the issues raised by the task impurity debate several different tasks are used to test the participants' executive control. Both the Test of Everyday Attention (TEA) (Robertson et al., 1994) and the AX- Continuous Performance Task (AX-CPT) (Locke & Braver, 2008; Morales et al., 2013; Paxton, Barck, Racine & Braver, 2008) are tasks used to test inhibition. The TEA has the advantage of being an auditory task, which is closer to the bilingual experience. The AX-CPT, on the other hand, differentiates between two types of inhibition: reactive and proactive inhibition. Reactive inhibition is the inhibition triggered in response to an immediate stimulus, while proactive inhibition is activated for a specific task and maintained until the task is over. Both tasks are explained further in Chapter 2 (2.2.2). The use of two tasks intended to test the same mechanisms of executive control (inhibition) reinforces the validity of any results found.

In addition to the mechanisms of executive control discussed (inhibition and switching), a task designed to examine visuospatial abilities is included, the results of which will be demonstrated in the second study (Chapter 3). The Corsi Block-Tapping Tasks (Corsi, 1972), which previous research has used to test working memory and visuospatial abilities (Antoniou et al., 2016; Emmorey et al., 2017; Keehner & Gathercole, 2007), are used to compare monolingual and bilingual groups, including the English, Maltese and Arabic groups. Three slightly different versions of the Corsi Block-Tapping Task are used: Corsi Forwards, Corsi Backwards and Corsi Rotated (detailed in 3.2.2). The first two have been regularly utilised in previous research focusing on working memory (Cornoldi & Mammarella, 2008; Luo et al. 2013). A recent study by Kerrigan et al. (2017) showed bilinguals outperforming monolinguals on both the Corsi Forwards and Backwards. The third Corsi task, Corsi Rotated, has gained momentum in recent literature. It taps into visuospatial abilities in addition to working memory components (Keehner & Gathercole, 2007). Visuospatial abilities are defined as cognitive processes that analyse space relations in detailed form (Bradford & Atri, 2014). Working memory is a cognitive system that processes information while simultaneously involved with attentional demands, distractions or other similar processes (Baddeley & Hitch, 1974; Engle et al., 1999).

Studies on working memory have shown bilinguals outperforming their monolingual peers (Bialystok et al., 2004; Blom et al., 2014). For example, a paper by Morales, Calvo & Bialystok (2013) compared monolingual and bilingual children regarding several working memory tasks and found that the bilingual children outperformed their monolingual peers in both a Simon-type task and a visuospatial span task. Furthermore, the bilingual effects were more evident when the tasks' demands increased. Several other studies, however, found no working memory effects in bilinguals (Bialystok et al., 2008; Feng, 2009; Namazi & Thordardottir, 2010; Abreu, 2011). Regardless in order to control for working memory effects in Study II, differences found between the Corsi Rotated and the Corsi Backwards are also considered. Therefore results found may be confined to visuospatial effects.

Emmorey et al. (2017) concluded that domains related to linguistic working memory and spatial working memory are correlated. They tested bimodal bilinguals on linguistics and spatial working memory tasks, including the Corsi Block-Tapping Task in Forward and Backwards mode. They concluded that when an effect on bilinguals' ability on spatial tasks is shown there may also be an effect of working memory. Related to performances on spatial reasoning, several studies have shown bilinguals outperforming their monolingual peers in tasks looking at perspective taking. Greenberg, Bellana & Bialystok (2013) found that bilingual children were more accurate in identifying an observer's view of a four-block array than their monolingual peers. Meanwhile, a study utilising the Corsi Rotated Block-Tapping Task on bimodal bilinguals showed that the bilinguals knowing both spoken and sign language performed better on the Corsi Rotated than the non-signers (Keehner & Gathercole, 2007).

Since previous research has shown bilinguals outperforming monolinguals on inhibition and switching, this thesis examines whether biliteracy specifically affects these two functions. In Chapter 2, a comparison is made between two similar groups of bilinguals that distinctly differ on script (Maltese/English bilinguals and Arabic/English bilinguals) in order to study the specific effects of biliteracy on inhibition and switching. In Chapter 3, further research compares these groups regarding their working memory and visuospatial ability, in order to see whether the biliteracy of the Arabic/English affects visuospatial ability. The results indicate that the Arabic speakers, regardless of bilingualism, showed a significant advantage in the Corsi Rotated not found in any of the other languages examined. This leads to a discussion on linguistic diversity, further detailed in the next section (1.3)

1.3 Effects of Linguistic Diversity and Linguistic Distance

In this thesis the term 'linguistic diversity' refers to languages that differ in a number of characteristics. Despite the rise of global English and the reduction of many minority languages, the world nevertheless remains multilingual. In fact, internet websites in popular languages are increasing, with Arabic, for example, increasing by 8,616.0% since 2000 becoming the Internet's fourth most used language compared to English at 649.7% since 2000, (statista, 2017; IWS, 2017). Thus, multilingualism is likely to continue for a very long time. Given languages' different characteristics, research should focus more on comparing different languages thereby offering new insights on language diversity and not merely comparing different language groups as replications of an original study. A simple Google Scholar search shows that current linguistic research on English speakers outnumbers research on Arabic speakers by more than ten-fold[1] Population-wise however, the number of English speakers is only three times more than Arabic speakers. Generalising results done only on English speakers to all languages does account for the different characteristics of languages, such as orthography, grammar, vocabulary, and the effects these may have on executive control.

In our second study, for example, we compared English monolinguals, Arabic monolinguals, Maltese/English bilinguals, and Arabic/English bilinguals on three Corsi Block Tapping Tasks, the last of which examines visuospatial abilities. Visuospatial abilities are commonly tested using children, bimodal bilinguals or intellectually challenged individuals and, to our knowledge, have never been investigated in the context of language-specific effects. The study revealed that Arabic affects mental rotation tasks such as the Corsi Rotated Task, regardless of bilingualism. Since the effects were also found in the Arabic monolinguals, this reiterates that they are language specific, and had the study compared the bilingual

[1] Google Scholar search found on 06.12.18. Key words: 'linguistics: English speakers' About 1,370,000 results, 'linguistics: Arabic speakers' About 118,000 results.

groups to only English monolinguals, the results could have been mistakenly attributed to bilingual effects. Since few studies have looked at language-specific executive control differences, this could also explain the differing results found in research on bilingual effects. Languages have different characteristics and therefore may constantly utilise distinctive components of executive control, which may lead to the diverse effects found in terms of bilingual studies.

Furthermore, linguistic diversity may influence results on bilingual effects, considering that languages' different characteristics may mean that different language combinations may exhibit varying results on tasks related to executive control. Therefore, the linguistic distance between languages may have an effect not previously considered in research, and knowledge of two varying languages may exhibit additional differences on executive control than knowledge of languages with similar characteristics. 'Linguistic distance' refers to the diversity between two languages such as language family, grammar, and vocabulary. This thesis will examine whether the linguistic distance caused by script adding an extra level of complexity leads to differing effects between two such groups (Maltese/English and Arabic/English bilinguals). Although there is no conclusive way to measure the difference between two languages, many linguists differentiated between languages using language families and common ancestral links, both detailed in section 1.2 regarding English, Maltese and Arabic.

Linguistic distance has been especially important to research concerning second language learning and the ease with which a language is acquired. A paper by Hart-Gonzalez and Lindemann (1993) measured linguistic distance by analysing different elements of proficiency among English-speaking Americans of average ability after fixed periods (16 weeks and 24 weeks) of foreign language training. The scores in relation to the difficulty of learning a language with English as a native language, ranged from 1.00 to 3.00, with 1 being languages that were harder to learn (e.g., Japanese), and 3 for languages that were easier to learn (e.g., Swedish). This study emphasizes the cognitive strain of learning dissimilar languages on a person, and reiterates that not all language combinations can be treated as equal in bilinguals.

Concerning this finding, and taking into consideration language families and the Hart-Gonzalez and Lindemann (1993) study, English will be compared with Maltese and Arabic. Arabic was scored a 1.50 on the Hart-Gonzalez scale compared to English, reiterating its acquisition difficulty. Whether linguistic distance is measured using the Hart-Gonzalez and Lindemann's (1993) approach or language trees, ample evidence indicates that the linguistic distance between English and Arabic is greater than the distance between English and Maltese, as the script itself adds complexity.

1.4 Hemispheric Variance in Distinguishing Morphological Markers

In the final study (Chapter 4), hemispheric differences in distinguishing morphological markers in English, Maltese and Arabic, are examined. Although research has shown that the left hemisphere of the brain is dominant in most language related tasks, studies investigating morphological processing in non-Indo-European languages have found an effect of complex morphology relying on right hemisphere involvement (Palti, Ben-Shachar, Hendler & Hadar, 2007; Feldman, Frost & Pnini, 1995; Prunet, Beland & Idrissi, 2000). The importance of the different script direction in Semitic languages found by Ibrahim & Eviatar (2007), suggested that Semitic languages, such as Arabic and Hebrew, employ the use of both brain hemispheres in distinguishing morphological markers when reading. In contrast, English readers rely on the left hemisphere. The researchers calculated response time and accuracy by using a Lexical Decision Task in order to determine morphological processing in both hemispheres by speakers of English, Arabic and Hebrew. The task displayed a word or non-word on the screen and participants were required to identify whether it was a correct word or a non-word. The study tested English, Hebrew and Arabic speaking groups using three versions of the task, one in each language. The English, Hebrew or Arabic words were presented unilaterally, either on the left or right side of the screen. Ibrahim et al. (2007) found that the English speakers relied on the left hemisphere for distinguishing morphological markers, while the Arabic and Hebrew speakers utilised both hemispheres. The authors also argued that lexical decisions are influenced by language experience since English-Hebrew bilinguals utilise both brain hemispheres when making a lexical decision in both English and Hebrew. In contrast, English monolinguals would only utilise the left hemisphere when making lexical decisions in English (Eviatar & Ibrahim, 2007).

In response to these studies, a biliteracy and hemispheric variance study was added to this thesis. The comparison of Arabic and Maltese will attempt to distinguish the influence of script directionality. The thesis investigates whether hemispheric variance is due to script differences by comparing monolingual English speakers, monolingual Arabic speakers, English/ Maltese Bilinguals and English/ Arabic bilinguals. The bilingual groups will further address whether the effects of one language are transferred to the other. In addition, although previous studies only used a visual Lexical Decision Task, we also use an auditory Lexical Decision Task. Although the auditory cortex is not as distinctly split as the visual field, it is closer to the bilingual experience and may enable further insights as to the hemispheric differences between the three language groups.

Summary

This thesis conducts three studies comparing English, Maltese and Arabic speakers on three major components of cognitive functions: executive control, mental rotation and in distinguishing morphological markers. The three languages were chosen due to their unique characteristics that, when compared, will help distinguish the effect of script on tasks. Since Maltese and Arabic share a wide range of characteristics but differ on script, which Maltese has in common with English, comparing Maltese/English bilinguals and Arabic/English bilinguals will help distinguish biliteracy effects. Specific effects on executive control, such as inhibition, switching and visuospatial abilities, are based on previous research showing bilingualism's effects on executive control, which showed that bilinguals may outperform monolinguals on non-linguistic tasks. Since the results of the second study reveal that Arabic speakers, regardless of bilingualism, outperform on visuospatial tasks, the effects of linguistic diversity are discussed along with the effects arising from unique language characteristics. Furthermore, since languages themselves display unique characteristics, the linguistic distance between a bilingual person's two languages may also lead to unique effects on cognitive functions. Finally, the third study is derived from previous research comparing differences in how the two hemispheres of the brain are used by Arabic, Hebrew and English speakers when distinguishing morphological markers. This previous work has maintained that Arabic and Hebrew employ both hemispheres in distinguishing morphological markers, while English relies only on the left hemisphere (1.4). Comparing the Maltese and Arabic groups will help distinguish whether the effects found in the original study were due to script or specific morphological effects.

Chapter 2
Study I: Effects of Biliteracies on the Executive Control of Lifelong Bilinguals and Language Learners

2.1 Study I Introduction

As detailed in Chapter 1 (1.2), research on the relationship between bilingualism and cognitive functions has shown bilinguals outperforming monolinguals on certain cognitive function tasks, specifically those related to executive control. Although previous research accounted for individual differences between bilinguals, such as age of acquisition and language usage, this thesis examines language differences and whether there are specific script effects on executive control tasks.

The study is composed of two experiments in order to examine whether biliteracy has specific effects on executive control related to inhibition and switching in both lifelong bilinguals and late language learners. The effects of biliteracy on inhibition and switching are examined using two main executive control tasks, three subsets of the *Test of Everyday Attention*, and the *AX continuous performance task* (AX-CPT) designed to compare different types of inhibition. The three subsets of the Test of Everyday Attention are: the *Elevator Task* (ET), the *Elevator Task with Distraction* (ETD), and *the Elevator Task with Switching* (ETS). ET is a counting task and acts as a control for the other tasks. ETD taps into functions related to inhibition, while ETS also includes switching effects in the task. The AX-CPT, however, tests two types of inhibition: reactive and proactive control. Both tasks are detailed in the methodology section (2.2.2).

Experiment 1 focuses on the effects of biliteracy on executive control in lifelong bilinguals. Four groups are used as a comparison: English monolinguals, Arabic monolinguals, English/Arabic bilinguals, and English/Maltese bilinguals, with all bilinguals having learned and consistently used both English and their respective language before the age of eight. As will be mentioned in the participants section, 2.2.2, the groups were recruited from Scotland, Malta and Saudi Arabia. The comparison focuses on the fact that, like English, Maltese uses the Latin script, while Arabic uses the more visually complex Arabic script (detailed in 1.1).

Experiment 2 compares groups learning their languages as adults, in order to examine whether proficiency and age of acquisition are also factors in biliteracy's effects on executive control. The groups examined were current university students in Scotland, studying either a humanities or social science programme (monolingual English speakers), a morphologically complex language written in the Latin script, or Arabic (detailed in 2.3.2). The students were also classified based on year of study, and yearly comparisons were done between the groups. Since Arabic is a morphologically complex language a comparison language was needed, but due to the limited availability of students learning a morphologically complex language that is written using the Latin alphabet several languages were tested (Gaelic, Turkish, Czech and Polish). Final group numbers however appeared inadequate; therefore analysis examined whether individual scores were significantly different from the control sample (monolingual English speakers or Arabic learners).

2.2 Experiment 1: Lifelong bilinguals

2.2.1 Introduction

This study replicates previous results and finds bilingual effects between the monolingual and bilingual groups. The study's objective is to distinguish specific script effects on executive control in order to examine whether bilinguals with knowledge of more than one script exhibit different effects on inhibition and switching tasks than bilinguals with languages that share a script, thereby also examining if more complex orthography leads to greater bilingual effects. In order to examine the effects of script on executive control, four groups were recruited: two monolingual groups (English and Arabic) and two bilingual groups (Arabic/English bilinguals, Maltese/English bilinguals). The groups were compared on a number of non-verbal tasks that tap into inhibition and switching, specifically AX-CPT and the TEA, in order to examine whether biliteracy distinctly affects executive control.

Initial predictions were that the Maltese bilinguals would outperform the two monolingual groups and that the Arabic bilinguals would outperform all groups since the complexity of the Arabic script would lead to further executive control effects. Based on research showing that even dialects may exhibit an effect on executive control, it was also hypothesized that the Arabic monolinguals might outperform the English monolinguals (Antoniou et al. 2016; Ibrahim & Aharon-Peretz, 2005; Poarch, Vanhove & Berthele, 2018).

2.2.2 Methodology

Participants

The first experiment includes four different groups: monolingual English speakers, monolingual Arabic speakers, English/ Maltese bilinguals, and English/ Arabic bilinguals. All groups were comprised of current university students. The monolingual English speakers were recruited from the University of Dundee in the UK, and the English/Maltese bilinguals were recruited from the University of Malta in Malta. The Arabic speakers were recruited from two universities in Riyadh, Saudi Arabia: the English/Arabic bilinguals from Prince Sultan University, and the Arabic monolinguals from King Saud University. The reason two universities in Saudi Arabia were chosen is that it was more convenient to find early, balanced English/ Arabic bilinguals in Prince Sultan University since their teaching material relies more heavily on English. As Malta is a bilingual country no Maltese monolinguals were available as an additional monolingual group. English monolinguals were originally recruited from the University of Edinburgh; however due to them significantly outperforming other groups on the Raven's Advanced Matrices, the recruitment source for monolinguals was changed to the University of Dundee. It was concluded that the University of Edinburgh students outperformed due to the University's stricter selection criteria.

Recruitment was carried out by email, by pamphlets distributed and exhibited in university public areas, class visits with a two-minute talk to encourage participation, as well as social media posts on Facebook and Twitter.

At the time of the study, all the recruited students were enrolled in a humanities or social sciences degree at their university. The bilinguals spoke both languages at a high proficiency, had learnt the second language, English, before the age of 8 and had continued to use it regularly since. Bilingual participants, whether Arabic or Maltese, rely on English in educational settings and Maltese or Arabic with family and friends. Media and reading material are consumed in both languages regularly and with ease by the bilingual participants. To control for general intelligence the Raven’s Advanced Matrices was used. A socioeconomic background questionnaire was also used with questions pertaining to both education and income. A language questionnaire was used to control for individual differences in language use, knowledge and acquisition. The participants’ characteristics are summarized in Table 2.1.

	Total (Female-Male)	Age Mean (SD)	Raven's Advanced Progressive Matrices Mean (SD)	Socioeconomic Status Mean (SD)
English monolinguals (UoD)	35 (26-9)	19.3 (1.3)	13.3 (3.6)	14.7 (2.81)
Arabic monolinguals	30 (18-10)	21.6 (1.4)	11.5 (4.6)	12.8 (2.39)
Maltese/English bilinguals	40 (33-7)	21.4 (4.2)	13.6 (4.1)	12.7 (2.97)
Arabic/English bilinguals	40 (34-6)	20.8 (1.6)	13.4 (4.3)	17.6 (2.26)

Table 2.1 [Study I, Experiment 1] Total number of participants with Mean and SD (in parentheses) for age, Raven’s score, and SES

Apparatus and Procedure

Participants’ Background: Raven's Advanced Progressive Matrices

The Raven's Advanced Progressive Matrices (Raven, 1936) is a non-verbal IQ test. In each question, the participant is asked to identify the missing piece that completes a pattern. The Test contains 48 questions, presented in two sets: 12 questions in set I and 36 in set II. As the participant progresses through the test the patterns become more difficult. The patterns are shown on a white background in black ink. For this study the participants were given 10 minutes to answer as many questions from Set II as they could. The instructor in English gave the instructions to all groups except for the Arabic monolinguals, where the instructions were given in

Arabic. The participants first completed an example before starting; then the instructor would leave them alone for ten minutes when they were required to complete as many patterns as they could from the booklet. The final score is the number of correct answers.

Participants' Background: Language and Socioeconomic Status (SES) Questionnaires

A language questionnaire assessed each participant's command of each language in terms of speaking, listening, reading and writing, based on a 5-point scale (basic/weak/moderate/advanced/fluent) for each domain. The language composite score was calculated by adding the proficiency levels in all four domains. There were also additional questions pertaining to command of their languages and their usage patterns. The questionnaires were in English or, in the case of the Arabic monolinguals, Arabic, and participants were asked to complete them at their leisure after they have finished all the tasks.

A socioeconomic status questionnaire asked the standard vocation and education questions regarding the student and their parents. It also asked about their household income and how likely the participant was to have access to educational aids, such as computers, when needed. The results were out of 25 as each parent's education status was worth 5; income was on a 10-point scale; and a 5-point scale asked how likely a participant was to have access to educational aids. Additional questions asked about a participant's schooling and their parents' vocation, but were not included in the scoring system as they were open-ended.

Both the Language and SES questionnaires are included in the Appendices (A.1 and A.2) .

In addition to the previous participant background tasks, the executive control tasks were also administered to each participant in no particular order so as to avoid fatigue.

AX-CPT Task

The AX-CPT is a version of the continuous performance task (Rosvold et al., 1956) that has been widely used to distinguish between reactive and proactive control (Locke & Braver, 2008; Morales et al., 2013; Paxton, Barck, Racine & Braver, 2008). Participants were consecutively shown a series of five different letters, starting and ending with a red letter, and with three white letters in-between. Each letter remained on the screen for 250ms or until the participant pressed ‘yes’ or ‘no’, as can be seen in Figure 2.1. Participants were asked to press ‘no’ for every letter, except when the 5 letter trial starts with a red A and ends with a red X, which is the target trial. The ‘yes’ and ‘no’ keys are counterbalanced so participants would randomly press either ‘Z’ for yes and ‘M’ for no, or vice versa. A short practice trial was given to participants before the actual task began. Since the testing process was over an hour long the standard AX-CPT task was shortened so that only half the standard task was used. This was done in order to limit participant fatigue. Although the task included written instructions, further verbal clarification was always given in English, or in Arabic to the Arabic monolinguals.

As previously stated, the AX-CPT task differentiates between two types of inhibition: reactive and proactive control. Proactive control indicates that a specific goal is established and complete focus is maintained for the entire duration inhibiting outside stimuli; whereas reactive control is the ability to inhibit a reaction response to a stimulus. As can be seen in Figure 2.2, there are four types of possible trials: *AX, AY, BX*, and *BY*. The trial names reflect the beginning and end letters, with ‘B’ and ‘Y’ representing any letter other than ‘A’ and ‘X’. The first and last letters appear on a black screen in red, while the middle letters are in white. The target trials AX appeared in 70% of the task duration, creating a default that is expected by the participants. The other three trials each appear for 10% of the duration. The AY trial shares the cue with the default AX trial and therefore participants expect an ‘X’ to appear. When they see another letter their failure to suppress their response shows a high reliance on proactive control and low reactive control. The opposite can be seen using the BX trial, as the participants need to maintain their proactive control and suppress their immediate reaction to press ‘yes’ upon seeing the target ‘X’. The final BY trial is a control as it does not share cues with the target AX trial.

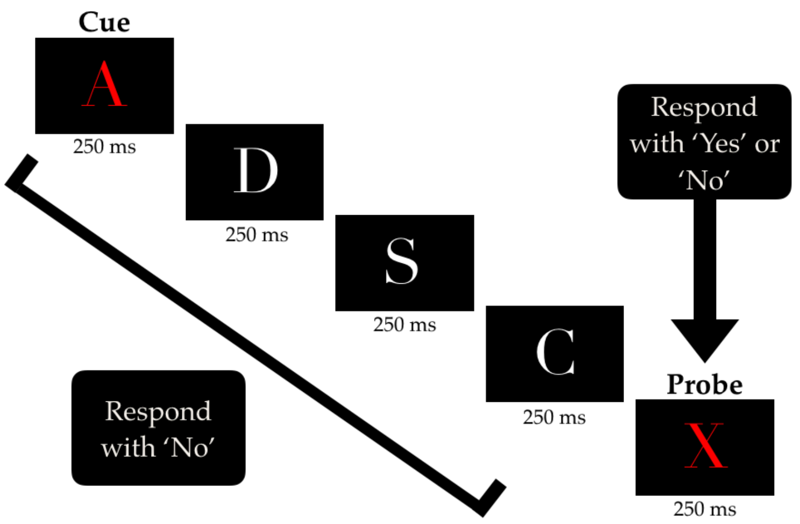

Figure 2.1 Representation of a single target trial during the AX-CPT task. Each square represents the screen. Correct response for probe is ‘Yes’.

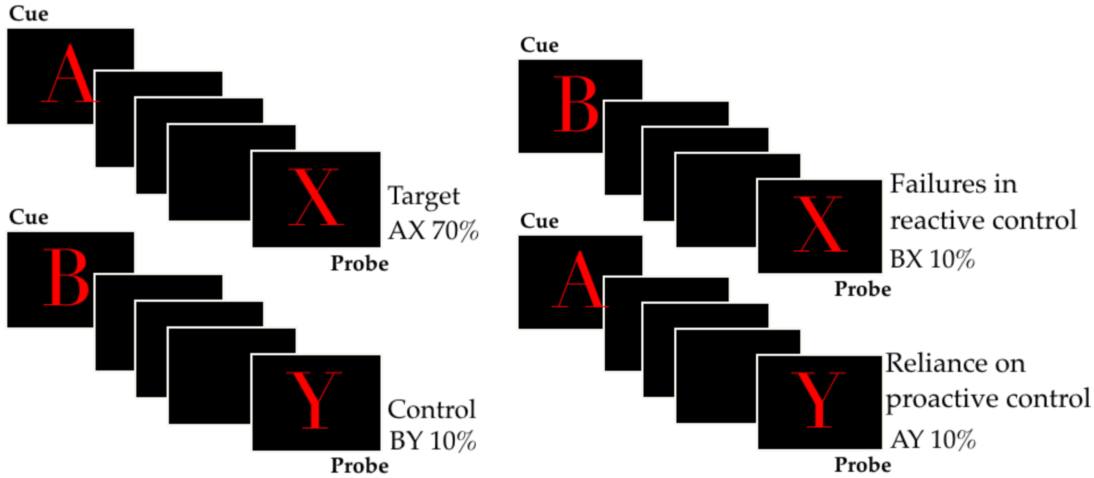

Figure 2.2 Representation of the four trials that appear during the AX-CPT task and the frequency of their appearance. The letters ‘B’ and ‘Y’ represent all other letters except for ‘A’ and ‘X’.

The Test of Everyday Attention (TEA)

Three subtests from the TEA (Robertson et al., 1994) were chosen: the *Elevator Task* (ET), the *Elevator Task with Distraction* (ETD), and the *Elevator Task with Switching* (ETS). Unlike the tasks commonly used for testing executive control in bilinguals, the Elevator Tasks have the advantage of using auditory cues which makes them, to a certain degree, similar to the bilingual experience.

In the *ET*, the participants were asked to pretend that they are in an elevator and must establish which floor they arrive at by counting a series of tones, varying from 5 to 14 tones. This task measures the participant's sustained attention. The second task, the *ETD* assesses inhibition: the participants were asked to count the low tones in the pretend elevator while ignoring or inhibiting the high tones. In the final task, the *ETS*, the participants had to count up and down in the pretend elevator depending on audible cues: if the participant hears a high tone they must count upwards, and if they hear a low tone they must reverse count. This task measures both the participant's inhibition and switching processes.

The elevator tasks were preceded by at least two examples, which had to be successfully completed before beginning the actual task. A self-assessment question was also added at the end of the second and third elevator tasks that asked, "Out of 10 how many do you think you answered correctly?". Further analysis will help us understand whether people under or over self-evaluate and whether this affects their performance.

All testing was done in a quiet private room on the participant's respective university campus. A 13-inch MacBook Pro with Retina display, and Sony MDR-ZX310 headphones with a 10–24,000Hz frequency range were used for tasks that required a screen or sound. The volume was left at 50%, although participants could change it based on their comfort.

2.2.3 Results

Analyses of Variance (ANOVAs) and independent t-tests were performed in order to compare mean differences between the groups. Paired t-tests were done to compare between participant's actual and self-assessed score. Correlational analyses was conducted using Pearson's correlation coefficients. Analyses of variables not meeting the assumption of normality were conducted using non-parametric tests, specifically the Kruskal-Wallis H test. Post hoc pairwise comparisons were carried out when appropriate.

The current data shows no bilingual effects, as the bilingual groups did not outperform the monolingual groups on either the TEA or the AX-CPT (all $ps > .05$). The data shows no significant difference between inhibition and switching associated with biliteracy, since there was no significant difference between the Maltese bilinguals and the Arabic bilinguals (all $ps > .05$). There was also no advantage observed for the Arabic monolinguals' usage of a different dialect as there was no difference between the Arabic monolinguals and English monolinguals regarding any of the tasks (all $ps > .05$)

Timed Raven's Advanced Progressive Matrices

The crucial aim was to control for general intelligence. This was achieved since the results showed no significant difference between any of the four groups regarding the number of correct answers on the timed Raven' s Advanced Progressive Matrices ($H(3) = 4$, $p = 0.2$). Mean performance and standard deviation for the Raven's Advanced Progressive Matrices can be seen in Figure 2.3 and above in Table 2.1.

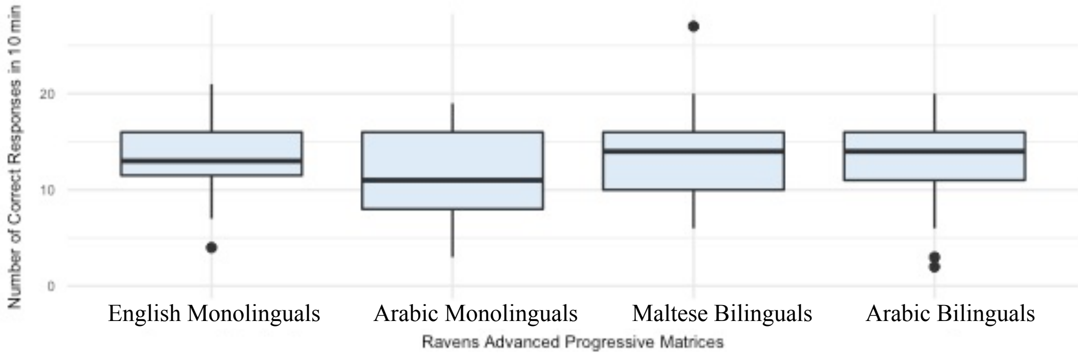

Figure 2.3 [Study I, Experiment 1] Mean and SD for Raven's Advanced Progressive Matrices

Socioeconomic Status Questionnaire (SES)

A significant difference was found in the groups' SES scores ($F(3, 114) = 23.17$, $p < .01$), since the Arabic/English bilinguals had the highest socioeconomic status (M= 17.6, SD= 2.26). While there was no difference between the Arabic monolinguals (M= 12.8, SD= 2.39) and the Maltese/English bilinguals (M= 12.7, SD= 2.97), the English monolinguals (M= 14.7, SD= 2.81) had a significantly higher socioeconomic status than the other two (both ps< .05). Mean performance, standard deviation and significant differences can be found in Figure 2.4 and above in Table 2.1.

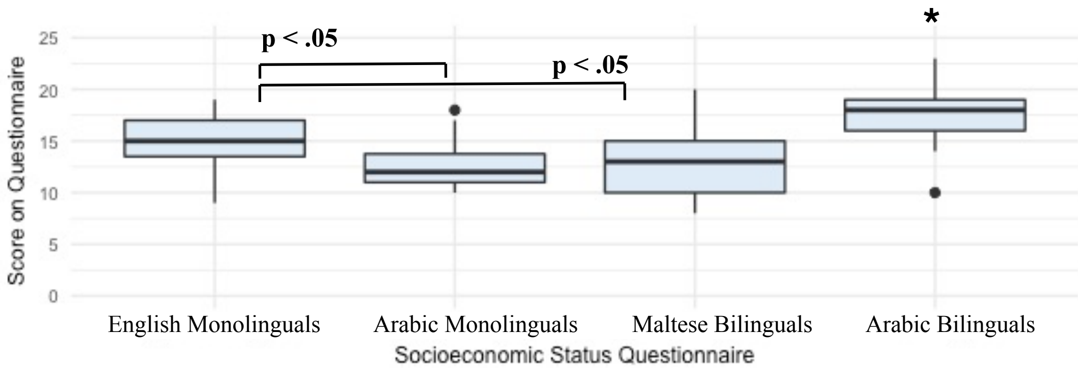

Figure 2.4 [Study I, Experiment 1] Mean and SD for Socioeconomic Status
* Outperforms all other groups p < .05

Test of Everyday Attention (TEA)

TEA 1: Elevator Task (ET) As expected, all participants performed at ceiling in the first ET and there was no significant difference between the groups (all ps< .05).

TEA 2: Elevator Task with Distraction (ETD). No significant difference was observed between any of the groups in the percentage of correct answers in the second elevator task, the ETD (H(3) = 2.9, p= 0.39). Participants tended to underestimate their results, as their self-assessment and actual results were correlated ($r(115) = .66$, $p < .001$) but significantly differed ($t(257) = 6$, $p < .001$) . Mean performance and standard deviation on the ETD can be seen in Figure 2.5.

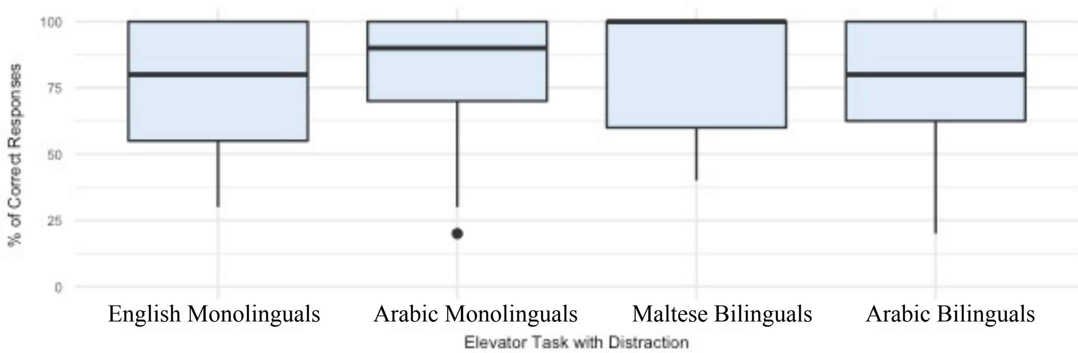

Figure 2.5 [Study I, Experiment 1] Mean and SD for Elevator Task with Distraction

TEA 3: Elevator Task with Switching (ETS). A significant group effect was found in the percentage of correct answers in the ETS (H(3) = 10.8, p= .01). Pairwise comparisons showed that the Arabic monolinguals (M=46.1, SD=32.5) were outperformed by both the Maltese bilinguals and the English monolinguals (all ps< .05). Mean performance, standard deviation and significant differences can be found in Figure 2.6. Participants again tended to underestimate themselves as they were significantly inaccurate in their self-assessment ($t(255) = 4.3$, $p < .001$), although there was a strong correlation between anticipated results and actual results ($r(115) = .67$, $p < .001$).

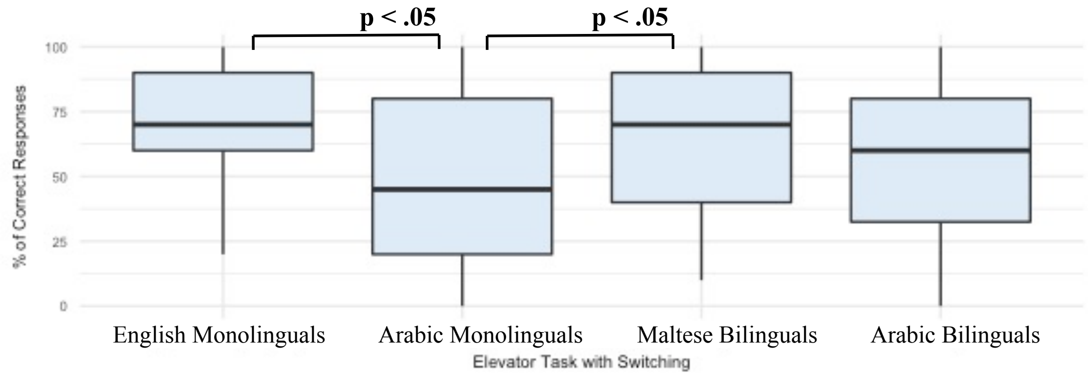

Figure 2.6 [Study I, Experiment 1] Mean and SD for Elevator Task with Switching

AX Continuous Performance Task (AX-CPT)

AX Trial. A significant group effect was found regarding the groups' accuracy on the AX trials (H(3) = 21.4, p< .001). Levene's Test indicated unequal variances (F=3.08, p= .02); therefore degrees of freedom were changed from 3 to 129. Non-pooled SD Pairwise comparison showed that the Arabic monolinguals and Arabic bilinguals were outperformed by the English monolinguals and the Maltese bilinguals (all ps< .05). There was no significant difference between the groups in the response time of the AX trials (H(3) = 5.1, p= 0.16).

AY Trial. There was no significant difference between the groups in the percentage of accurate answers in the AY trials (H(3) = 2.69, p= 0.44), nor in the response time of the AY trials (H(3) = 1.38, p= 0.7).

BX Trial. There was no significant difference between the groups in the percentage of accurate answers in the BX trials (H(3) = 3.52, p= 0.31), nor in the response time of the BX trials (H(3) = 5.38, p= 0.14). All groups performed faster on the BX:Reactive Control trial than the AY: Proactive Control trial.

BY Trial. There was no significant difference between the groups in the percentage of accurate answers in the BY trials (H(3) = 3.28, p= 0.34). A significant group effect, however, was found in the groups' response time on the BY trials (H(3) = 10.5, p= .01). Levene's Test indicated unequal variances (F=3.9, p< .001); therefore degrees of freedom were changed from 3 to 128. Non-pooled SD Pairwise comparison showed that the English monolinguals responded faster than all the other groups (all ps< .05).

A summary of mean performance, standard deviation and significant differences on accuracy and response time of all four trials can be found in Table 2.2.

Although there was no significant correlation between performance on BX and AY, the Arabic bilinguals performed better than all other groups on the BX trials (M=92, SD=13), whereas the Maltese bilinguals performed the best on the AY trials (M=75, SD=24) as can be seen in Figure 2.7. The difference nevertheless, was not significant.

	AX (SD)		**AY (SD)**		**BX (SD)**		**BY (SD)**	
	Accuracy	RT (ms)	Accuracy	RT (ms)	Accuracy	RT (ms)	Accuracy	RT (ms)
English monolinguals a	91.27 (5.1)	b 314.09 (25.6)	70.65 (22.8)	423.85 (97.8)	88.46 (14.1)	230.93 (70.4)	94.99 (12.1)	243.17 (65) *
Arabic monolinguals	81.15 (12)	c 334.86 (60)	68.48 (25.7)	433.55 (102.6)	82.48 (23.7)	274.21 (116.84)	90.5 (16.2)	332.53 (138.7)
Maltese/ English bilinguals	89.56 (8)	d 342.79 (59.7)	74.95 (24.1)	444.84 (109)	84.2 (18.4)	286.01 (126.4)	88.65 (17.2)	288.57 (101.2)
Arabic/ English bilinguals	82.94 (12.2)	338.43 (57.9)	66.41 (23.1)	451.1 (155.3)	91.56 (13.1)	269.73 (90.2)	88.41 (21)	289.42 (97.8)

Table 2.2 [Study I, Experiment 1] Mean and SD (in parentheses) on AX-CPT
* Outperforms all other groups in trial p < .05 a,b,c,d= p<.05

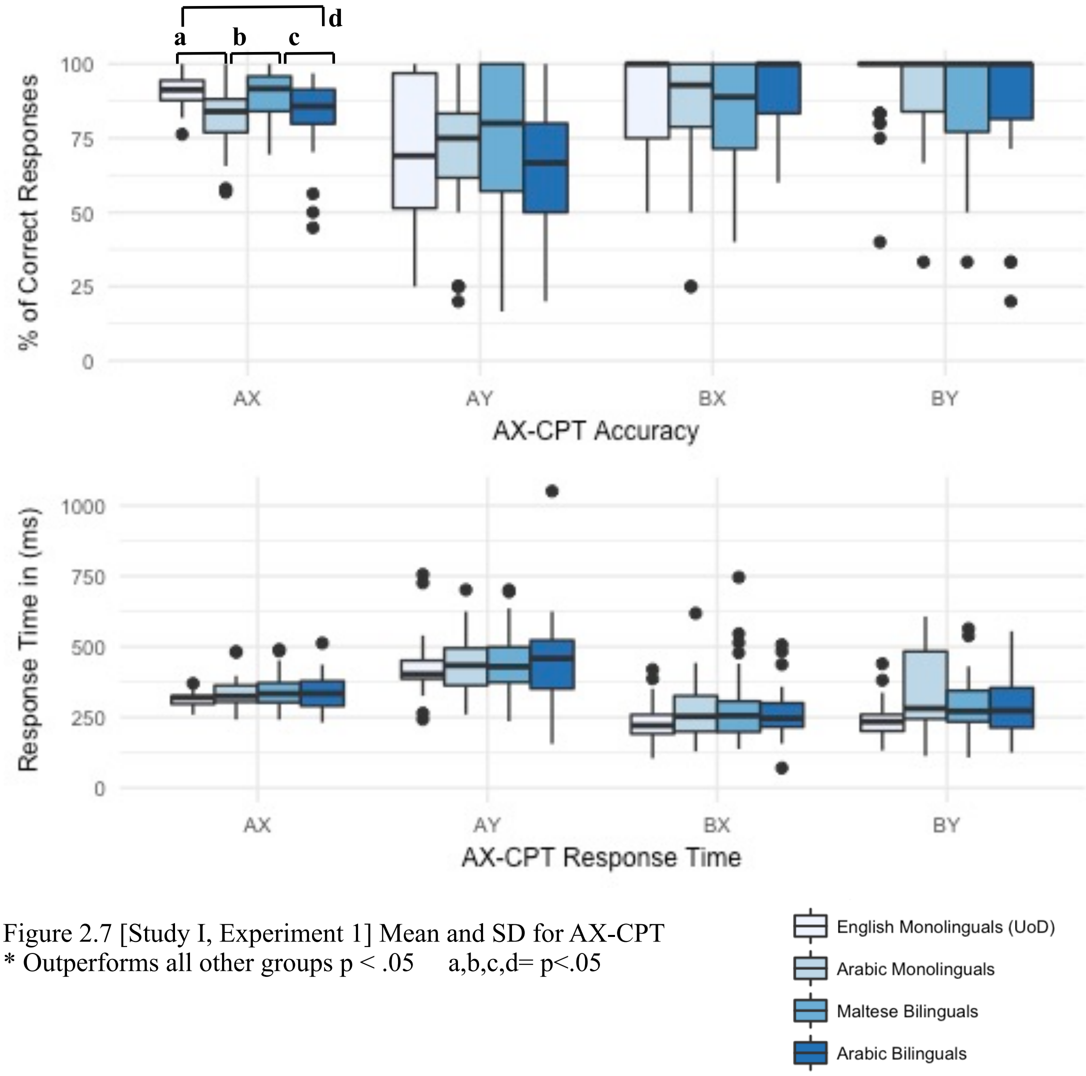

Figure 2.7 [Study I, Experiment 1] Mean and SD for AX-CPT
* Outperforms all other groups p < .05 a,b,c,d= p<.05

2.2.4 Discussion

This thesis examines the main effects of biliteracy on executive control in both lifelong and late bilinguals. Both the English monolinguals and Arabic/English bilinguals had a significantly higher socioeconomic status. However, the groups are equally distributed in terms of bilingual effects as one bilingual group and one monolingual group outperform the other pair.

After controlling for the Raven's Advanced Matrices, socioeconomic status and participants' language scores, bilingual effects were not found for any of the groups on any of the AX-CPT tasks, or the ETD. Nonetheless, both the Maltese bilinguals and the English monolinguals outperformed the Arabic monolinguals on the ETS. Since another monolingual group outperformed the Arabic monolinguals this may not be a result of bilingual effects in the case of the English/Maltese bilinguals but because the Arabic monolinguals underperformed generally. Although this task has indicated bilingual effects in previous research (Vega-Mendoza, West, Sorace & Bak (2015)).

Surprisingly, the Arabic bilinguals did not outperform any of the other groups, especially considering their higher socioeconomic status. Biliteracy itself, therefore, also shows no distinct advantages, since the Arabic bilinguals did not outperform the Maltese bilinguals on any of the tasks.

In this regard it should be noted that many papers have not been able to find bilingual effects in this specific age group. One explanation offered is that university students may already be operating at the highest level of executive control and thus may show a ceiling effect. Further differences may be palpable in older adults or children.

Although there was no significant correlation between performance on BX and AY, the Arabic bilinguals performed the best on the BX trials, whereas the Maltese bilinguals performed the best on the AY trials, although the difference was not significant. This may be because Arabic utilises a different writing form, more reliance is placed on reactive control than with Maltese readers, who must proactively inhibit their other language while reading since the script is the same. This difference on the AX-CPT sheds light on how different languages and their characteristics may utilise different kinds of inhibitions and why not all languages produce the same results. The difference in performance sheds light on the different ways inhibition is used in these two groups and reinforces the idea that bilingual effects are both group and task specific.

We hypothesized that the monolingual Arabic group will show an advantage over the monolingual English group and display similar results to that of bilingual effects, due to their dialect. This is based on previous research that found that Arabic speakers may process their two distinct dialects, the colloquial dialect and Modern Standard Arabic (detailed in 1.1), as different languages (Ibrahim & Aharon-Peretz, 2005). In our results, however, the Arabic monolinguals did not show any effect on performance in any of the inhibition or switching tasks.

Finally, the results do not conclusively reveal any bilingual effects with regard to the inhibition and switching tasks performed in this study. However, as no differences were found between the English/Maltese bilinguals and the English/Arabic bilinguals, there also appears to be no distinct effect of biliteracy and the everyday use of another script

2.2.5 Summary

While previous studies have shown bilinguals outperforming monolinguals on tasks related to inhibition and switching, this thesis study specifically addressed whether utilising two scripts on a daily basis affected performance on tasks relating to executive control. In order to study the effects of script, two distinct Semitic languages were chosen: Arabic and Maltese.

After controlling for general intelligence using the Raven's Advanced Matrices, and for socioeconomic status and participants' language scores, bilingual effects were not found for any of the groups on any of the AX-CPT tasks, or the ETD. On the other hand, the Maltese bilinguals and English monolinguals outperformed the Arabic monolinguals on the ETD. Since both bilingual groups did not outperform both monolingual groups there was no conclusive evidence of bilingual effects on tasks related to inhibition and switching. The results could have been due to the Arabic monolinguals Raven's scores: although the difference was not significant, the Arabic monolingual group had the lowest scores on the task related to general intelligence (Raven's Advanced Matrices). Biliteracy also shows no significant advantages as the Arabic/English bilinguals did not outperform the Maltese/English bilinguals on any of the tasks.

In conclusion, after controlling for confounding variables, this thesis was unable to show an effect of bilingualism on inhibition or switching. There is also no distinct advantage to the everyday utilisation of two scripts over one regarding the executive control tasks related to inhibition and switching, since the English/Maltese bilinguals and the English/Arabic bilinguals performed similarly.

2.3 Experiment 2: Language Learners

2.3.1 Introduction

Since Experiment 1 focused on lifelong bilinguals who had learned the language before the age of 8, in the next step we examined bilinguals learning the language at a later age, specifically in their university years. In addition, this thesis will be able to test students throughout their university years, gaining closer insight as to how four years of language learning at university influences scores on attention and inhibition tasks. Results may also show effects of language immersion on executive control as the students also spend their third year abroad, immersed in the respective languages' environment.

For this experiment, monolingual English speakers were compared with participants learning a language at university, either a morphologically complex language (Czech (2.00), Polish (2.00), Turkish (2.00), Gaelic); or students learning Arabic (1.50). While the languages taught to the students are morphologically complex, they all share the Latin script with English. The linguistic distance degree featured in some of the languages above was measured using the Hart-Gonzalez and Lindemann's (1993) approach as previously discussed in Chapter 1 (1.3). Instead of specifying one morphologically complex language, convenience dictated that several languages be used, as the language class sizes are quite small. The first group of languages (Czech, Polish, Turkish, Gaelic) was chosen because their morphology was increasingly complex compared to their native language English, and this complexity, while not identical to Arabic, was substantial enough to theorise additional hardships faced upon learning the language for native English speakers, as the Hart-Gonzalez and Lindemann's (1993) study showed.

Due to the relative infrequency of language learning in the languages chosen it was highly unlikely that the native English-speaking students would not already have learnt a more popular language, such as Spanish or French, beforehand. The majority of the participants learning the chosen languages at university already spoke an additional language, but only participants with languages written in the Latin script were tested, to specifically examine the effects of biliteracy on the participants.

In line with research showing an effect on attention and inhibition in bilinguals when compared to monolinguals, it was hypothesized that the students studying a language would outperform their monolingual peers. It was also anticipated that the Arabic learners would outperform the students studying a morphologically complex language due to a larger linguistic distance, including script. The Arabic learners were hypothesized to show an advantage at the end of their first year and continuing to increase up to their fourth year. Due to the majority of the language learners, (both in the morphologically complex languages group and the Arabic learners) having previous knowledge of another language, bilingual effects might be visible even before students completed their first year of language study.

Due to the limited number of participants in the morphologically complex languages group, however, analysis was done on an individual basis using a single case methodology approach.

2.3.2 Methodology

Participants

The participants for this study were divided into three groups: monolingual English speakers, students learning a morphologically complex language written in the Latin script, and students learning Arabic. All participants recruited were university students. The monolingual English speakers were recruited from several schools within The College of Humanities and Social Science at the University of Edinburgh.

The participants learning a morphologically complex language were recruited from two departments within The College of Humanities and Social Science: The Celtic and Scottish Studies Department for participants learning Gaelic, and the Islamic and Middle Eastern Studies Department for the students learning Turkish. Due to the limited availability of students in the two programmes (several classes only had one student), additional participants were recruited from the University of Glasgow. Students taking Central and East European Studies in Glasgow are given a choice of the following morphologically complex languages throughout their four years: Estonian, Hungarian, Latvian, Czech, and Polish. Although an attempt was made to recruit from all the stated morphologically complex languages, no students were available learning Estonian, Hungarian or Latvian. The final morphologically complex language learning group consisted of participants studying Gaelic (7), Turkish (3), Czech (1) and Polish (3). The third group is the students learning Arabic at the Islamic and Middle Eastern Studies Department.

The students studying languages are given approximately four hours of language classes a week. Depending on their major, the rest of their classes were history, politics, religion or literature. The students spend the third year of their studies abroad in a country that speaks the languages taught.

The participants were tested multiple times throughout the course of three years, starting in September/October during students' first and second year of undergraduate study. During April and May of each year, the second-year undergraduates were tested before they leave for their year or summer abroad. The sample size was smaller than expected after initial recruitment. For this reason, the study recruited participants every year and tested them hereafter, instead of testing the same sample longitudinally. A short summary of the participants' characteristics can be found in Table 2.3 and combined by language group in Table 2.4.

	1st Year			**2nd Year**			**4th Year**		
	Sex	**Age**	**Raven's**	**Sex**	**Age**	**Raven's**	**Sex**	**Age**	**Raven's**
English monolinguals	18F-4M	18.63	16.77	12F-5M	19.76	17.29	17F-7M	21.61	16.16
Morphologically complex language learners	8F-1M	20.3	16.7	4F	18.5	19.3	1F	29	20
Arabic language learners	11F-11M	20.6	17.23	6F-5M	19.8	16.57	8F-3M	21.3	14.25

Table 2.3 [Study I, Experiment 2] Total number of participants with Mean for age and Raven's score.

	Combined Groups		
	Sex (Female-Male)	**Age (SD)**	**Raven's (SD)**
English monolinguals	63 (47-16)	20.1 (1.5)	16.6 (4)
Morphologically Complex Language Learners	14 (13-1)	20.7 (3.2)	18 (2.9)
Arabic Language Learners	40 (21-19)	19.9 (1.5)	16.7 (3)

Table 2.4 [Study I, Experiment 2] Combined groups and total number of participants with Mean and SD (in parentheses) for age and Raven's score.

Two English monolinguals were excluded due to non-completion of tasks. An additional post-graduate group learning Arabic (11 students) was tested in order to compare the differences between the four-year language programme and a two-year master's programme. Due to the limited number of students, however, the results were inconclusive and were not used.

Apparatus and Procedure

The same executive control tasks were utilised to test the lifelong bilinguals: the AX-CPT, and the TEA. General intelligence was controlled with the Raven's Advanced Progressive Matrices, while language history was controlled with through the language questionnaire.

In the questionnaire administered to the participants learning Arabic, further questions were added: pertaining to why they were studying Arabic, if/why they chose to continue taking it, and what was the hardest part of studying Arabic. These additional questions were in response to the large number of students observed who chose to discontinue taking Arabic after their first year, which may present a selection bias. The results merely showed that students usually took Arabic classes as an elective and decided to discontinue taking it after the first semester due to the increasing difficulty or time issues.

Experiment 2 was administered on the University of Edinburgh campus or, for the University of Glasgow students, in the Mitchell Library in Glasgow; a 15-minute walk from the campus, making it convenient and comfortable for the students. Each participant was tested individually, and the researcher remained with the participant throughout the duration of the testing, except during the timed Raven's and the AX-CPT task.. The tasks themselves were administered randomly in order to avoid fatigue. Completion time was about one hour, after which participants would be asked to complete the Language Questionnaire at their leisure.

In the pilot study, language proficiency was determined by requiring participants to view pictures and choose the correct term describing it. Due to the competing nature of Arabic dialects, however, many words were unidentified, even though the participant may know the word in another dialect. In addition, the majority of participants were political studies majors, and while easily distinguishing political high-functioning words were unable to correctly identify everyday objects.

The language questionnaire was therefore used to score their proficiency in a language.

2.3.3 Results

Due to the difficulty of recruiting students learning Arabic and students learning a morphologically complex language, the participants were not as high as originally anticipated and therefore a single case methodology approach was utilised to analyse the data. The three groups within each individual language group were based on how many years the participants had been studying the language: 1, 2 or 4 at university. The third year was excluded as participants were on their year abroad.

In order to accommodate the small numbers within the groups, the program Singlims_ES.exe was used to account for the significance of executive control effects in the groups. This program tests whether an individual's score is significantly different from a control or normative sample (Crawford, Garthwaite & Porter, 2010). The control sample in this case was the English monolinguals to both bilingual groups, and the Arabic group to the Morphologically Complex Language group. The program compares an individual participant's score to the control sample and provides an estimate of the control population performing differently (Crawford, 2006). The program also accounts for each participant added in the language groups and adjusts group means and standard deviations accordingly. When the data was run through this program, however, no significant differences were found between any of the groups on both the AX-CPT and the TEA (all ps< .05).

In an effort to test the groups as a larger unit, the students were combined based on the languages they were learning regardless of their year of study. This combination resulted in three groups: English monolinguals (n=63), Learners of a Morphologically Complex Language (n=14), and Arabic Learners (n=44). The ANOVA results, however, revealed no significant difference between the three groups on the TEA tasks, the ETD ($H(2) = 1.85$, $p= 0.39$), or on the ETS ($H(2) = 2.2$, $p= 0.33$). Pertaining to the AX-CPT, the results showed that, although there was no difference in response time between the groups on the AX trial ($H(2) =.06$, $p=.96$), the English monolinguals were less accurate than the Arabic Learners ($p<.01$). No other difference was detected between the remaining groups ($H(2) = 9.8$, $p<.01$). In the AY trial, meanwhile, no difference was detected on either response time ($H(2) = 1.3$, $p= 0.51$) or accuracy ($H(2) = .09$, $p= 0.95$). There was also no difference in response time ($H(2) = 1$, $p= 0.58$) and accuracy ($H(2) = .24$, $p= 0.88$) for the BY trial, or the response time ($H(2) = 1$, $p= 0.59$) and accuracy ($H(2) = 3.1$, $p= 0.2$) for the BX trial.

2.3.4 Discussion

To observe whether learning a different script shows distinct effects on executive control, a comparison was made between students studying a morphologically complex language, Arabic, and monolingual English speakers. The groups were tested on two facets of executive control related to inhibition and switching, using two tasks: namely, the AX-CPT and three subsets of the TEA. The groups were categorised by language groups and compared based on year of study. The results revealed no significant bilingual or biliteracy effects between any of the groups in respect to either of the tasks. Due to the small numbers in each group, statistical testing of the results using standard methods were unavailable. Based on the current data, however, the single case analysis showed that the bilingual groups did not outperform the monolingual group, and that biliteracy does not show a distinct effect on executive control tasks, since the Arabic learners did not outperform the morphologically complex language group. Since no effect of bilingualism was found it is maintained that university students are already performing at the height of their executive control abilities and therefore any effect would be minimal at best. In addition, as observed in Experiment 1 on lifelong bilinguals, acquiring of a different script does not show significant effects in attention or inhibition. Perhaps testing older learners or children would result in clearer answers. The difficulty of recruiting students may also have affected results as participants had to be recruited from both Edinburgh and Glasgow, as well as with a large mixture of languages for the morphologically complex language groups. Although it would be extremely difficult to control for these issues, doing so would potentially provide greater insight. Since the experiment had originally been planned as a longitudinal analysis study involving the testing of the same students twice yearly for four years, the shortage of numbers and the high dropout rate of Arabic learners after the first year meant that it was impossible in practice to execute a longitudinal analysis study. Had the study been a longitudinal analysis the results would have been much clearer. Due to the small numbers of participants definitive results were not found for the effect of immersion in language learning on non-linguistic tasks, such as those targeting inhibition and switching. If future studies could take this into account, and learn from this experiment, a clearer study could perhaps be undertaken.

2.3.5 Summary

In this experiment an attempt was made to observe bilingual effects and, specifically, biliteracy effects in language learners during their university years. The participants tested were university students studying either Arabic or a language that is morphologically complex but uses the Latin script. A comparison was done between English monolinguals, native English speakers studying a morphologically complex language, and native English speakers studying Arabic, on inhibition and switching tasks, specifically the AX-CPT and the TEA. Language groups were compared as a whole, as well as categorised based on years of study. Due to the small number of participants the results were analysed using a single case methodology, but there was no significant effect arising from bilingualism since there was no difference between the English monolinguals and the bilingual groups. Further group analysis using standard methods also revealed no differences between the groups. There was also no apparent effect to learning a new script on tasks related to inhibition and switching as results showed both the Arabic learners and the students learning a morphologically complex language performing similarly.

2.4 Study I Conclusion

In this study, an attempt was made to examine whether biliteracy and the learning of an additional script has a distinct effect on executive control such as inhibition and switching. In order to test this hypothesis, two experiments were done on lifelong bilinguals and language learners. The same tasks and procedures were utilised in both and the main confounding variables, such as general intelligence, SES and language history were controlled.

For the first experiment, the study focused on comparing Arabic and Maltese, since both languages share a number of characteristics. The four groups: English monolinguals, Arabic monolinguals, English/Maltese bilinguals and English/Arabic bilinguals, were tested on executive control tasks related to inhibition and switching. The AX-CPT task tested different types of inhibition while the Elevator Task tapped into both inhibition and switching. While it was hypothesized that the English/Arabic bilinguals would outperform the other groups, and that the monolingual groups would perform the worst, the results showed no effects of bilingualism as the bilingual groups did not outperform the monolingual groups. There was also no effect of biliteracy since the Arabic/English bilinguals did not outperform the Maltese/English bilinguals.

The second experiment focused on students learning a language during their university years and compared students learning a morphologically complex language written in the Latin script to Arabic, to see if acquiring a new writing system affects performance on tasks related to inhibition or switching. Due to the small group sizes, however, it was not possible to use regular statistical methods to analyse the results and therefore a single case method was used instead to compare the groups. Again, however, no bilingual effects were discernible between the English monolinguals and the bilingual groups, nor was there a biliteracy effect between the Arabic learners and the Morphologically Complex Language Learners.

Upon further analysis into the English monolinguals, both those from the University of Edinburgh and the University of Dundee, we found that while there was no significant difference between their Raven's score, the monolinguals who had at least one bilingual parent ($n=22$, $M=15$, $SD=3.9$) tended to outperform monolinguals with monolingual parents ($n=42$, $M=13.8$, $SD= 4.2$), on the ETD ($H(1) = 4.3$, $p=.03$) but not on the ETS ($p>.05$). While the results are minimal and there is certainly not enough background information on the participants' parents to account for immigration and fluency, this could provide an interesting starting point for further studies. Further research should provide data while controlling for aspects such as general intelligence, usage of the language (such as whether the parents spoke the language in front of the child while the child was not encouraged to learn it), and whether there is an immigration bias.

The current language choices are successfully matched in order to test biliteracy but perhaps testing other age groups might provide better insights as to whether biliteracy has a distinct effect on executive control. Due to the long nature of the overall testing only half of the standard AX-CPT task was used. However, the task revealed no significant results. The use of the longer 30-minute task might have taxed the participants and led to results showing the participants at less than perfect abilities.

In conclusion, while the study did not show bilingual effects after controlling for general intelligence, SES and language background, there is no distinct advantage to learning a different script on inhibition or switching. This may provide insights for future research as to specific language effects that may contribute to bilingual effects.

Chapter 3
Study II: Effects of Arabic on Mental Rotation

3.1 Study II Introduction

In the second part of this thesis, the research continues to examine the effects biliteracy has on cognitive functions, focusing specifically on visuospatial abilities such as mental rotation. The effects on mental rotation are examined using three Corsi Block Tapping Tasks: Forwards, Backwards and Rotated. The tasks utilise working memory, in addition to mental rotation, and require participants to mimic sequences with increasing difficulty. Study II consists of three experiments, all of which utilise the Corsi tasks in order to examine whether script has specific effects on mental rotation, shown regardless of bilingualism.

The first experiment compares the English monolinguals, Arabic monolinguals, Maltese/English bilinguals, and Arabic/English bilinguals in order to observe the specific effects of script on mental rotation. As detailed in Chapter 1 (1.1), although Arabic and Maltese share many characteristics, Maltese utilises the Latin script, while Arabic uses the Arabic script, thereby possibly attributing any differences found between Maltese/English bilinguals and Arabic/English bilinguals to biliteracy effects arising from the latter's need to use a complex additional script in addition to the Latin script.

The second experiment investigates the exact script characteristic that affect mental rotation. Chinese was therefore chosen in order to observe whether writing directionality led to the effects found in Experiment 1. Given that Arabic is written from right-to-left, and English and Maltese are written from left-to-right, the addition of the directionality fluid Chinese will aid in observing script directionality on mental rotation. In addition to the groups in Experiment 1, Chinese monolinguals, Chinese low proficiency bilinguals and Chinese high proficiency bilinguals were compared in order to investigate whether familiarity with the Chinese script leads to similar results as found in the Arabic speakers.

In the third experiment, the Corsi Block Tapping Tasks were utilised to observe whether the results found in Experiment 1 regarding Arabic monolinguals and Arabic/English bilinguals can be seen in late learners of Arabic. Students studying Arabic at university were compared using the Corsi Block Tapping Tasks throughout four years of study (excluding their third year abroad) in order to see whether similar results were apparent in non-lifelong bilinguals.

3.2 Experiment 1: Lifelong bilinguals

3.2.1 Introduction

In order to examine the effects of script on mental rotation, a comparison was done between monolinguals and lifelong bilinguals, speaking English, Maltese or Arabic, on three Corsi tasks; Corsi Forwards, Corsi Backwards, and Corsi Rotated. The four groups are detailed in the previous chapter (2.2.2). Previous research has shown bilinguals outperforming monolinguals on tasks related to spatial reasoning and memory (detailed in 1.2) and thus it was hypothesized that the bilingual groups would outperform the monolingual groups, and that the Arabic/English bilinguals would outperform the Maltese/English bilinguals, since a difference in script leads to a greater linguistic distance with English.

Original predictions were that all three groups would perform the highest on the Corsi Forwards task and then the Corsi Backwards, and that the lowest results would be found on the Corsi Rotated, due to the higher degree of difficulty. Further predictions were that the monolinguals would perform less well than the other groups on all three Corsi tasks, and that the Maltese bilinguals would outperform the two monolingual groups, with the Arabic bilinguals outperforming all three groups. Since studies have shown that bidialectalism has an effect similar to bilingual effects (Antoniou et al., 2016; Ibrahim & Aharon-Peretz, 2005; Poarch et al., 2018), and since Arabic monolinguals regularly utilise at least two dialects throughout their life, an effect of bidialectalism was also taken into consideration since it was expected that the Arabic monolinguals would outperform the English monolinguals.

3.2.2 Methodology

Participants

The same lifelong bilingual participants were utilised as detailed in the previous study (2.2.2): namely, monolingual English speakers, monolingual Arabic speakers, Maltese/English bilinguals and Arabic/English bilinguals. Participants' characteristics are summarized in Table 3.1.

Three participants from the Arabic/English groups were excluded due to non-completion of the Corsi Block-Tapping task.

	Total (Female-Male)	Age Mean (SD)	Raven's Advanced Progressive Matrices Mean (SD)	Socioeconomic Status Mean (SD)
English monolinguals (UoD)	35 (26-9)	19.3 (1.3)	13.3 (3.6)	14.7 (2.81)
Arabic monolinguals	30 (18-10)	21.6 (1.4)	11.5 (4.6)	12.8 (2.39)
Maltese/English bilinguals	40 (33-7)	21.4 (4.2)	13.6 (4.1)	12.7 (2.97)
Arabic/English bilinguals	37 (31-6)	20.7 (1.5)	13.3 (4.4)	17.5 (2.2)

Table 3.1 [Study II, Experiment 1] Total number of participants with Mean and SD (in parentheses) for age, Raven's score, and SES

Apparatus and Procedure

The experiment was administered in a quiet room in the respective groups' university: University of Dundee for the English monolinguals, University of Malta for the Maltese/English bilinguals, Prince Sultan University for the Arabic/English bilinguals, and King Said University for the Arabic monolinguals. Since the Corsi tasks were administered with the other experiments in Study I (Experiment 1) the tasks themselves were administered randomly to avoid fatigue at the end of the testing period, which could have affected the results. Completion time for the complete testing session was approximately 50 minutes, after which participants would be asked to complete the Language and SES Questionnaires at their leisure.

The same background procedures administered in Chapter 2 (2.2.2) were utilised here, i.e., the Raven's Advanced Progressive Matrices, socioeconomic status (SES) and language questionnaire.

Participants' Background: Raven's Advanced Progressive Matrices, SES and Language Questionnaire

Both the Raven's Advanced Progressive Matrices and the SES and Language Questionnaires were detailed in the previous study and can be found in Chapter 2 (2.2.2).

Corsi Block-Tapping Tasks (Forwards, Backwards and Rotated):

The Corsi Rotated task is an extension of the Forward and Backward Block-Tapping Task from the widely used Corsi block-tapping tasks (Corsi, 1972).The Forwards and Backwards tasks use one board, while the Rotated Version utilises two boards. The tasks are administered on a board that has ten identical spatially separated blocks. The instructor and the participants sit facing each other with the board in the middle. The front of the board with the numbers always faces the instructor. The instructor taps the numbers corresponding to the numbers in the score sheets. The participant then attempts to repeat the pattern while the instructor registers the numbers of the blocks being tapped. Mean and standard deviation of the participants' scores on all three Corsi Block Tapping Tasks are summarized in Table 3.2.

	Corsi Forwards (out of 16)	Corsi Backwards (out of 16)	Corsi Rotated (out of 30)
English monolinguals (UoD)	7.86 (1.5)	6.60 (1.8)	10.9 (2.7)
Arabic monolinguals	7.13 (2.7)	5.60 (2.8)	13.2 (5.4)
Maltese/English bilinguals	7.40 (1.6)	6.85 (1.4)	11.3 (3.4)
Arabic/English bilinguals	7.86 (2.1)	6.97 (2.3)	16.1 (2.8)

Table 3.2 [Study II, Experiment 1] Mean and SD (in parentheses) on Corsi Block Tapping tasks

The Corsi Forward Block-Tapping Task uses a board with ten identical spatially separated blocks. The participants are asked to imitate as the instructor taps a pattern using the blocks. The pattern starts out simple, using two blocks, but becomes more difficult. The instructor continues until the participant incorrectly responds to one complete item (i.e., two trials consecutively). The final score (Corsi Span) is the number of complete correct trials out of the total 16. Instructions for The Corsi Forward Block-Tapping Task: *"In this next task I will point to a series of blocks, please point at the exact same blocks in the same order"*

The Corsi Backward Block-Tapping Task uses the same blocks but participants are asked to imitate the pattern done by the instructor backwards, i.e., starting from the final tapped blocked to the first. The pattern again starts out simple, using two blocks, but becomes more difficult. The instructor continues until the participant incorrectly responds to one complete item (two trials consecutively). The final score (Corsi Span) is the number of complete correct trials out of the total 16 trials. Instructions for The Corsi Backward Block-Tapping Task: *"In this task I will continue pointing to a series of blocks, please point at the exact same blocks however in reverse order."*

The Corsi Rotated Block- Tapping Task uses two boards instead of one. The instructor's board is rotated 180 degrees from the participants board and the participant must imitate what is being tapped on the instructor's board. In both boards the numbers face the instructor. The instructor begins with one block and does examples until the participants correctly answer all four examples. The task continues unless the participant incorrectly responds to one complete item (in this case six trials consecutively). The final score is the number of complete correct trials out of the total 30 trials.

3.2.3 Results

The R statistical package (R Development Core Team, version 3.4.3) was used to conduct Analyses of Variance (ANOVAs) to compare mean differences between groups. Analyses of variables not meeting the assumption of normality were conducted using non-parametric tests, specifically the Kruskal-Wallis H test. Post hoc pairwise comparisons were carried out when appropriate. Results on the timed Ravens and the SES are the same as those in Chapter 2 (2.2.3), but are briefly reiterated below.

Timed Raven's Advanced Progressive Matrices

The objective was to control for general intelligence. The results showed no significant difference between any of the four groups' number of correct answers on the test of general intelligence ($H(3) = 4$, $p = 0.2$).

Socioeconomic Status Questionnaire (SES)

A significant difference was found in the groups' SES scores ($F(3, 114) = 23.17$, $p < .01$), as the Arabic/English bilinguals had the highest socioeconomic status ($M = 17.6$, $SD = 2.26$). Also, while there was no difference between the Arabic monolinguals ($M = 12.8$, $SD = 2.39$) and the Maltese/English bilinguals ($M = 12.7$, $SD = 2.97$), the English monolinguals ($M = 14.7$, $SD = 2.81$) showed a significantly higher socioeconomic status than both of them (both $ps < .05$).

Corsi Block Tapping Tasks

Corsi 1: Corsi Forwards. No significant group effect was found in the Corsi Forwards *F*(3, 138) = 1.05, *p*=.3, as all groups performed similarly. Mean performance and standard deviation are presented in Figure 3.1.

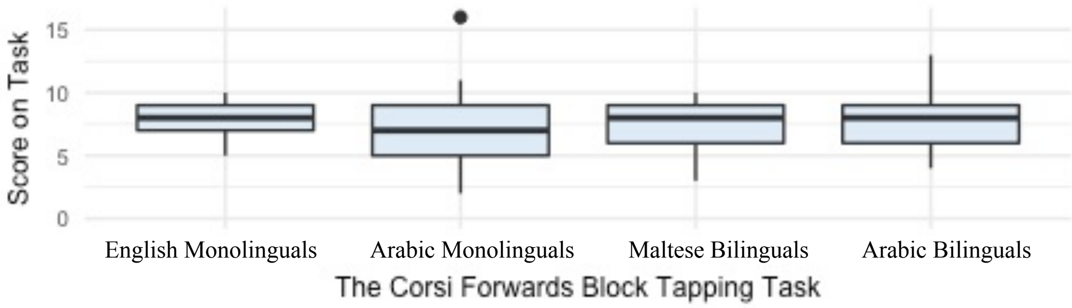

Figure 3.1 [Study II, Experiment 1] Mean and SD Corsi Forwards

Corsi 2: Corsi Backwards. A slightly significant group effect was found in the Corsi Backwards F(3, 138) = 2.73, p=.04. However Pooled SD Pairwise comparison showed no significant difference between the Arabic monolinguals (M=5.60, SD= 2.8), the Maltese/English bilinguals (M=6.85, SD= 1.4) and the Arabic/English bilinguals (M=6.97, SD= 2.3) (both ps= .05). Mean performance and standard deviation are shown in Figure 3.2.

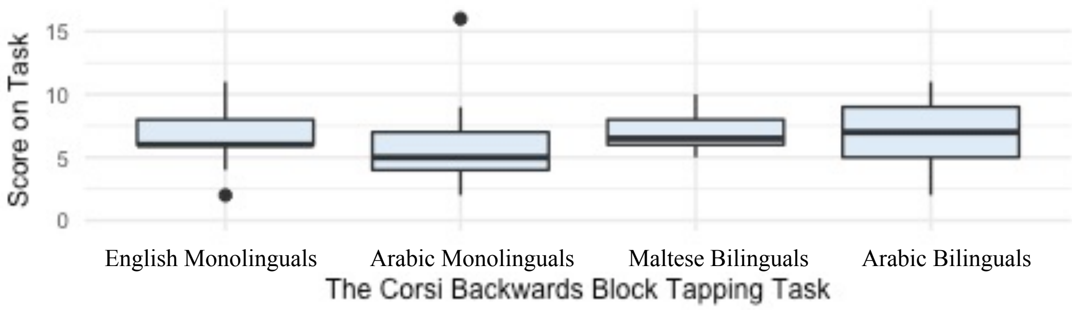

Figure 3.2 [Study II, Experiment 1] Mean and SD Corsi Backwards

Corsi 3: Corsi Rotated A significant group effect was found in the Corsi Rotated $F(3, 138) = 15.47$, $p<.001$. Pairwise comparisons showed that the Arabic bilinguals, with the highest mean performance (M=16.1, SD=2.8), outperformed all other groups (all ps< .001). While the Arabic monolinguals (M=13.2, SD=5.4) outperformed the English monolinguals (M=10.9, SD=2.7) and Maltese/English bilinguals (M=11.3, SD=3.4) (both ps< .05). Mean performance, standard deviation and significant results are presented in Figure 3.3.

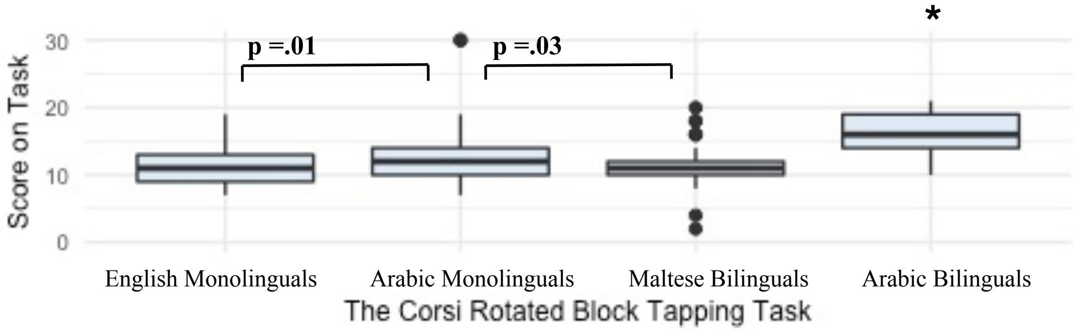

Figure 3.3 [Study II, Experiment 1] Mean and SD Corsi Rotated
* Outperform all other groups in trial p < .001

A clear pattern is shown when looking at the groups' performance across all three tasks. The English monolinguals' and the Maltese/English bilinguals' performance deteriorated as the tasks progressed. However the Arabic groups (Arabic monolinguals and Arabic/English bilinguals), performed better on the third Corsi than the second one. The trend in all four groups, on all three Corsi tasks, can be seen in Figure 3.4. In order to better visually represent the trend in Corsi results, results are displayed in percentages.

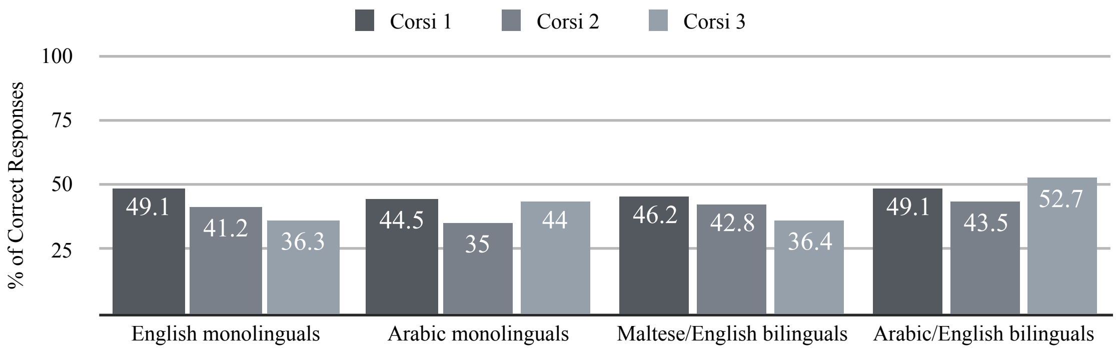

Figure 3.4 [Study II, Experiment 1] Patterns in Corsi Block Tapping Tasks

3.2.4 Discussion

A comparison was performed between English monolinguals', Arabic monolinguals', Maltese/English bilinguals' and Arabic/English bilinguals' performance on three Corsi tasks: Corsi Forwards, Backwards and Rotated. The tasks measure a combination of working memory and spatial reasoning. Although each group had more females and therefore were controlled for gender, previous studies suggest no gender difference for Corsi, and therefore it should have no effect (Pagulayan et al., 2007). The groups differed on socioeconomic status, as both the Arabic/English bilinguals and the English monolinguals scored higher than the Arabic monolinguals and the Maltese/English bilinguals. Since both a bilingual and a monolingual group exhibited either high socioeconomic status or low, with one Arabic group in each, the effects remain strong. After taking measures to control for general intelligence, the results found that the Arabic speakers, whether monolingual or bilingual, outperformed the other groups on the Corsi Rotated task. Given the hypothesis that only the bilinguals would outperform and show bilingual effects on all three tasks, the results were surprising and showed that while different languages utilise different cognitive functions, is correct, it is regardless of bilingualism.

Since all groups performed similarly on the Corsi Forwards test, which assesses non-verbal visuospatial memory, this shows a baseline that all groups share similar working memory abilities; specifically, all participants are able to recall information in the same format in which presented. Since there were no differences between the monolingual and bilingual groups, however, no effect was found that could be ascribed to bilingualism.

Although some research has suggested that there is no difference in the cognitive ability required for the Corsi Forwards and Backwards tasks (Kessels et al., 2008; Wilde and Strauss, 2002), other research has suggested that participants with low spatial abilities performed lower in the Corsi Backward task (Cornoldi and Mammarella, 2008; Garcia et al., 2014). While all the groups performed similarly on the Corsi Forwards, the Arabic monolinguals slightly underperformed compared to the other groups. While the Arabic monolinguals are able to mimic the block tapping in the same format it was presented in, it is harder for them when the task requires manipulation of the recalled information, or more reliance on working memory. Although both the bilingual groups outperformed the Arabic monolinguals this difference could not be interpreted as a bilingual effect since both bilingual groups performed similarly to the English monolinguals. The underperformance of the Arabic monolinguals could be due to a number of factors: most notably, although it was not significant, the Arabic monolinguals scored lowest on the Ravens task on general intelligence. A more likely explanation, however, is that the Arabic monolinguals were unable to both remember the Corsi span and perform it backwards as their switching abilities were lower than the other groups, recalling the evidence from Study I that showed that the Arabic monolinguals underperformed on the Elevator Task with Switching (Chapter 2; Experiment 1.1).

The most interesting results were in the Corsi Rotated, where, although both bilingual groups were expected to outperform both the monolingual groups, it was found that the Arabic monolingual and the Arabic/English bilingual groups outperformed the English monolinguals and the Maltese/English groups. The Arabic speaking groups performed similarly to the other groups, or slightly worse in the case of the Arabic monolinguals, on the Forwards and Corsi Backwards, and also showed the same pattern originally anticipated that the participants would perform worse with each Corsi task (i.e., progressing from Forwards to Backwards to Rotated Corsi), since the tasks theoretically should have become more difficult to complete correctly. Instead of following the pattern set by the English monolinguals and Maltese/English bilinguals, however, i.e., performing the best on the Corsi Forwards, slightly worse on the Corsi Backwards, and worst on the Corsi Rotated, the Arabic monolinguals and the Arabic/English bilinguals performed better on the Corsi Rotated than the Corsi Backwards. This is interesting as it reiterates the main point that bilingual effects may be language specific and that languages themselves may have specific individual requirements that show effects differently based on the tasks and their requirements.

This leads to the hypothesis that bilingual effects are the result of the acquisition of a second language that requires reliance on different mechanisms of executive control than the first language. The language acquired adds to the current language utilisation of executive control, and changes depending on the language's needs, which is why different languages utilise different components of executive control. Here, the unique spatial advantage observed could be a feature of Arabic arising from the complexity of Arabic orthography, since research has shown that the Arabic script is harder to process than the English and Hebrew (Ibrahim, 2011).

A simplified example would be if 'L1' monolinguals utilise inhibition and switching, and 'L2' monolinguals, utilise inhibition and visuospatial abilities, a L1/L2 bilingual would show effects of inhibition from both languages, switching due to L1 and visuospatial abilities from their knowledge of L2. This possibility could lead to language specific abilities being attributed as bilingual effects, and could explain a number of conflicting results found in bilingualism.

These results show that Arabic speakers exhibit an effect on tasks related to visuospatial abilities regardless of bilingualism, since the Arabic monolinguals showed the same advantage on visuospatial abilities. Furthermore, this effect is not due to morphological complexity since the Maltese/English bilinguals did not show a similar advantage on the Corsi Rotated, even though Maltese shares a large degree of Arabic's morphological complexity.

3.2.5 Summary

Utilising the Corsi Forward, Backwards and Rotated Tasks, four groups were tested: English monolinguals, Arabic monolinguals, Maltese/English bilinguals and Arabic/English bilinguals. Although my initial hypotheses anticipated bilingual effects for the two bilingual groups compared with the monolingual groups, the results indicated that all groups performed similarly on the working memory tasks: i.e., the Corsi Forwards and the Corsi Backwards.

On the Corsi Rotated, however, which taps into visuospatial abilities, the Arabic monolinguals and the Arabic/English bilinguals outperformed the Maltese/English bilinguals and the English monolinguals. This effect, related to visuospatial abilities, is apparent regardless of bilingualism since the Arabic monolinguals showed the same advantage on visuospatial abilities. The effect is also not due to morphological complexity since the Maltese/English bilinguals did not show a similar advantage on the Corsi Rotated, even though Maltese shares a large degree of Arabic's morphological complexity. While the results on the Corsi tasks did not show bilingual effects, the results on the Corsi Rotated reiterated that task advantages seen in previous studies may be language and task specific.

3.3 Experiment 2: Arabic and Chinese Scripts

3.3.1 Introduction

The previous study examining script effects on mental rotation in English, Maltese and Arabic speaking groups found that Arabic speakers outperformed Maltese and English speakers on mental rotation. The results are not due to bilingualism since Arabic monolinguals showed the same pattern; nor are the results due to morphological complexity, since Maltese bilinguals did not show a similar pattern, despite having a similar morphology to Arabic. In order to examine the specific script characteristics that led to the effects found on the mental rotation tasks, another language group was needed in order to more specifically assess orthographic complexity. Both Maltese and English are written from left-to-right, while Arabic is written from right-to-left; hence in order to distinguish the possible effects of writing directionality on mental rotation Chinese groups were added to the original comparison groups. In addition, Chinese was added after finding that neither bilingualism nor morphological complexity explained the effect found in Arabic speakers on the Corsi Rotated task.

Chinese can be written both vertically and horizontally, both left-to-right and right-to-left. Although the dominance of Western media has increased left-to-right writing in Chinese, signs, historic scripts, and newspaper headlines, may still be found written from right-to-left. The addition of Chinese speakers gives an opportunity to distinguish the effects of script on the Corsi Rotated since Chinese can also be written from right-to-left and has a complex typography. Unlike Arabic, however, the complexity of Chinese script follows a structural order, whereas in Arabic handwriting the integral dots for the letters and the diacritical vowel markers may be ambiguously placed, specifically in more artistic calligraphic instances such as architectural art or the Quran. In choosing Chinese as a comparison, therefore, it will be possible to assess whether directionality, typographical complexity or lenient structural rules exhibit the effects found in the Arabic speakers in the Corsi Rotated task. The Chinese groups also have an advantage pertaining to whether proficiency affects the Corsi tasks since the Chinese participants are distinctly grouped into high proficiency and low proficiency bilinguals. The Chinese groups were recruited and tested by Helen XIA Lihua.

In accordance with the results found in Experiment 1 (3.2.3), similar results were hypothesized for all groups. While bilingual effects may be found, based on the previous experiment, all groups are predicted to perform similarly on the working memory tasks: the Corsi Forwards and Backwards. In other words, the three monolingual groups: English, Arabic and Chinese will perform similarly to the remaining bilingual groups (Arabic/English bilinguals, Maltese/English bilinguals, low proficiency Chinese bilinguals and high proficiency Chinese bilinguals). On the third Corsi task, the Corsi Rotated, Chinese bilinguals were predicted to show a similar effect to the English monolinguals and Maltese/English bilinguals as the advantage found in the Arabic speakers may be due to the structural fluidity of the script. If an effect was found in the Chinese bilinguals it may have meant that writing directionality or complexity of the script explains the effects found in the Arabic speakers.

3.3.2 Methodology

Participants

For this experiment the Chinese groups were added to the previously tested four groups described in 2.2.2 (English monolinguals, Arabic monolinguals, Maltese/ English bilinguals, and Arabic/English bilinguals). The Chinese groups include Chinese monolinguals, Chinese low proficiency (LP) bilinguals and Chinese high proficiency (HP) bilinguals. Every effort was made to ensure that all instructions, scoring and material for the Chinese groups were equivalent to that applied to the previously tested groups. All groups consisted of current university students. Both Chinese monolinguals and bilinguals were recruited from Hubei University. The monolingual Chinese group and the Chinese low-proficiency bilingual group were recruited from first-year undergraduates, while the Chinese high-proficiency bilingual group was recruited from fourth year undergraduate and first-year master's students. The bilingual groups were recruited from students studying English as a major, while the monolingual group were recruited from majors related to physical education, humanities or social sciences. All the Chinese bilinguals recruited were late bilinguals and although they had been exposed to English from age 8, this exposure was confined to the classroom. Recruitment was done by email, pamphlets distributed and hung in university public areas, class visits with a two-minute talk to encourage students to participate, as well as social media posts on the Chinese versions of Facebook and WhatsApp. Participants' characteristics are summarized in Table 3.3.

	Total (Female-Male)	Age Mean (SD)	Raven's Advanced Progressive Matrices Mean (SD)
English monolinguals (UoD)	35 (26-9)	19.3 (1.3)	13.3 (3.6)
Arabic monolinguals	30 (18-10)	21.6 (1.4)	11.5 (4.6)
Maltese/English bilinguals	40 (33-7)	21.4 (4.2)	13.6 (4.1)
Arabic/English bilinguals	37 (31-6)	20.7 (1.5)	13.3 (4.4)
Chinese monolinguals	61 (26-35)	18.75 (1.2)	15.4 (3.4)
Chinese (LP) bilinguals	30 (27-3)	18.17 (.6)	16.1 |(3.4)
Chinese (HP) bilinguals	30 (28-2)	21.47 (1)	15.4 (3.8)

Table 3.3 [Study II, Experiment 2] Total number of participants with Mean and SD (in parentheses) for age, Raven's score, and SES

Apparatus and Procedure

The same measures used in the previous experiment were utilised for this comparison: background measures such as the timed Raven' s Advanced Progressive Matrices and the Language Questionnaire. The participants were also compared on the three tasks successfully used previously: Corsi Forwards, Backwards and Rotated. As mentioned previously, instructions were given by the instructor in English to all the original groups except for the Arabic monolinguals, where the instructions were given in Arabic. For the Chinese participants, the tasks were conducted and given in Chinese by the instructor. Mean and standard deviation of the participants' scores on all three Corsi Block Tapping Tasks are summarized in Table 3.4.

	Corsi Forwards (out of 16)	Corsi Backwards (out of 16)	Corsi Rotated (out of 30)
English monolinguals (UoD)	7.86 (1.5)	6.60 (1.8)	10.9 (2.7)
Arabic monolinguals	7.13 (2.7)	5.60 (2.8)	13.2 (5.4)
Maltese/English bilinguals	7.40 (1.6)	6.85 (1.4)	11.3 (3.4)
Arabic/English bilinguals	7.86 (2.1)	6.97 (2.3)	16.1 (2.8)
Chinese monolinguals	8.34 (1.4)	7.39 (1.5)	12 (3.7)
Chinese (LP) bilinguals	8.67 (1.3)	7.17 (1.9)	11.3 (4.3)
Chinese (HP) bilinguals	8.80 (1.4)	6.67 (1.7)	10.8 (3.5)

Table 3.4 [Study II, Experiment 2] Mean and SD (in parentheses) on Corsi Block Tapping tasks

3.3.3 Results

- Timed Raven's Advanced Progressive Matrices

Although there is no significant difference between any of the four lifelong bilingual groups (all ps> .05), upon the addition of the Chinese groups a significant difference was detected (H(6) = 29.7, p < .001). Pairwise adjusted p-value comparisons showed the High Proficiency (HP) Chinese bilingual group outperformed the Arabic monolinguals (p< .001), with both the Low Proficiency (LP) Chinese bilingual group and the monolingual Chinese Group outperforming all four Lifelong bilinguals Groups (all ps< .05). Mean performance, standard deviation and significant differences are presented in Figure 3.5.

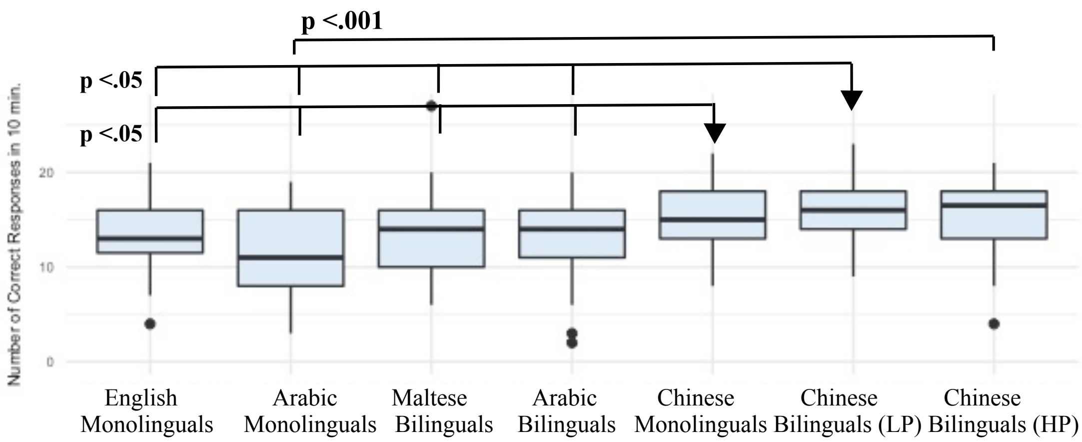

Figure 3.5 [Study II, Experiment 2] Mean and SD for Raven's Advanced Progressive Matrices

- Corsi Block Tapping Task

Corsi 1: Corsi Forwards A significant group effect was found in the Corsi Forwards (H(6) = 24.8, p< .001). Levene's Test indicated unequal variances (F=3.6, p<.01); therefore degrees of freedom were changed from 6 to 256. Non-pooled SD Pairwise comparison showed that the Arabic monolinguals, with the lowest mean performance at (M=7.13, SD= 2.7), and the Maltese bilinguals (M=7.40, SD= 1.6), were outperformed by both HP and LP bilingual Chinese groups (all ps< .05). The English monolinguals (M=7.86, SD= 1.5) were also outperformed by the highest performing group, the HP Chinese bilinguals (M=8.80, SD= 1.4) (p= .04), while the Maltese bilinguals were also outperformed by the Chinese monolinguals (p= .02). Mean performance, standard deviation and significant differences are presented in Figure 3.6.

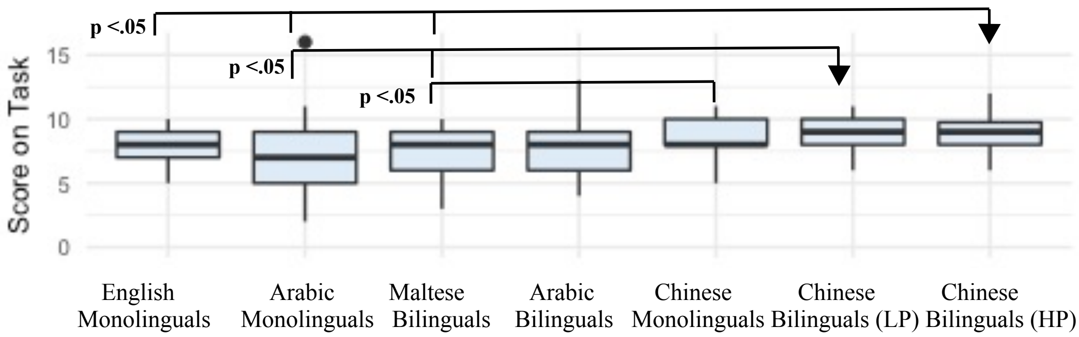

Figure 3.6 [Study II, Experiment 2] Mean and SD for Corsi Forwards

Corsi 2: Corsi Backwards A significant group effect was found in the Corsi Backwards (H(6) = 21, p< .01). Levene's Test indicated unequal variances (F=2.3, p= .03); therefore degrees of freedom were changed from 6 to 256. Non-pooled SD Pairwise comparison, however, showed no significant differences between any of the groups (all ps>.05). The Arabic monolinguals, with the lowest mean performance at (M=5.60 , SD= 2.87), were almost outperformed by the highest performing group, the Chinese monolinguals (M=7.39 , SD= 1.5) (p=.059). Mean performance and standard deviation are shown in Figure 3.7.

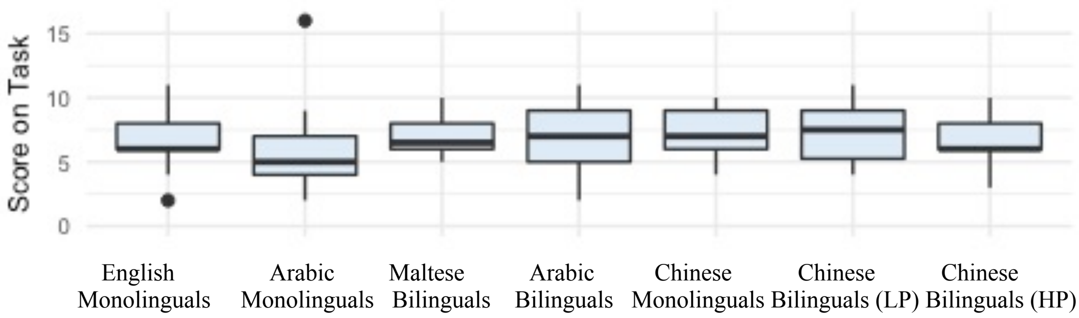

Figure 3.7 [Study II, Experiment 2] Mean and SD for Corsi Backwards

Corsi 3: Corsi Rotated A significant group effect was found in the Corsi Rotated (H(6) = 50.28, p< .001). Pairwise comparisons showed that the Arabic bilinguals (M=16.1, SD=2.8), outperformed all the other groups (all ps< .001). The

Arabic monolinguals however (M=13.2, SD=5.4) outperformed all other groups except for the Chinese monolinguals (M=12, SD=3.7) and the LP Chinese bilinguals (M=11.3, SD=4.3), and the Maltese/English bilinguals (M=11.3, SD=3.4), (all ps< . 05). Mean performance, standard deviation and significant differences can be found in Figure 3.8.

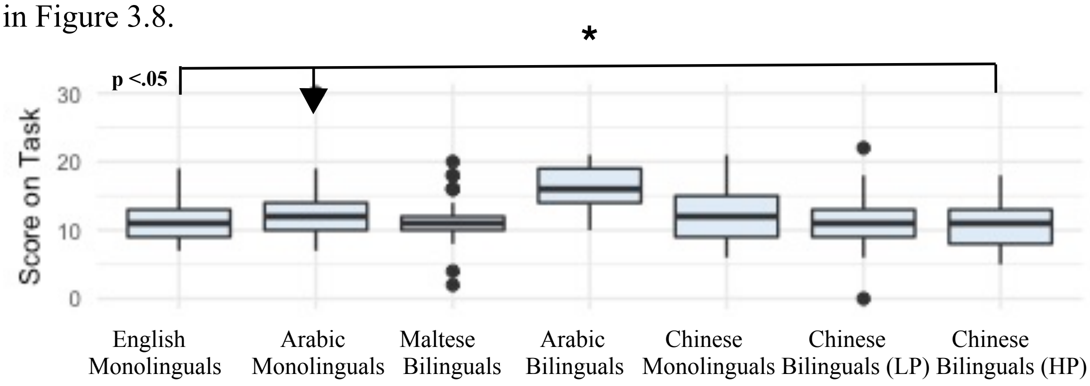

Figure 3.8 [Study II, Experiment 2] Mean and SD for Corsi Rotated
* Outperform all other groups p < .05 in Trial

If the performance of the groups on the Corsi Backwards is considered (since both the Backwards and the Corsi Rotated utilise working memory) and looking at the participants' improvement from the Corsi Backwards to the Corsi Rotated, the Arabic monolinguals, as well as the previously stated Arabic bilinguals, outperformed all other groups (H(6) = 49.74, p< .001).

A similar pattern to the one found in the previous experiment was therefore evident here. The performance of the groups deteriorates as the tasks progress, except for the Arabic groups. The Arabic monolinguals and Arabic/English bilinguals perform better on the third Corsi than the second one. The pattern can be seen in Figure 3.9. In order to better visually represent the trend in Corsi results, results are displayed in percentages.

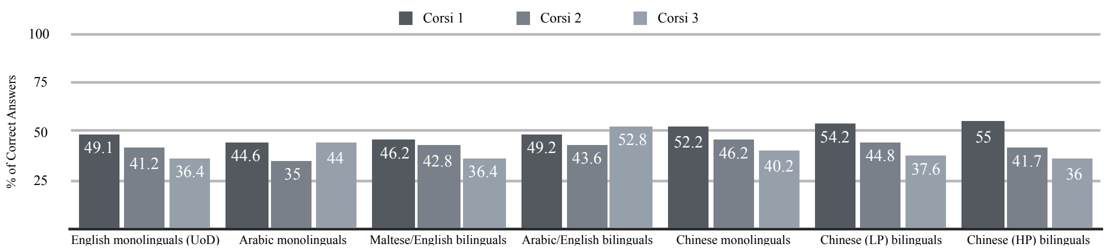

Figure 3.9 [Study II, Experiment 2] Patterns in Corsi Block Tapping Tasks

3.3.4 Discussion

The results found in the previous experiment (3.2) are replicated with the addition of the Chinese language in order to examine what exactly in the script influenced the higher performance found in Arabic speakers on the Corsi Rotated task related to visuospatial abilities. Employing three versions of the Corsi Block Tapping Task, the data from the previous experiment was utilised with the addition of Chinese monolingual, high proficiency Chinese/English bilingual, and low proficiency Chinese/English bilingual groups. Experiment 1 found that while the English monolingual, Arabic monolingual, Maltese/English bilingual and Arabic/English bilingual groups all performed similarly on the first two Corsi tasks (Forwards and Backwards), the Arabic speakers outperformed in the Corsi Rotated task. Since the effect was found in both Arabic bilinguals and the Arabic monolinguals, but not in the Maltese bilinguals, it cannot be due to bilingual effects; and since the Maltese bilinguals did not also outperform, it cannot be due to morphological complexity, since Maltese shares the Arabic morphological complexity. The effect is attributed to script differences, since the major difference between Arabic and Maltese is script because Arabic is written in its own script while Maltese utilises the Latin script.

In order to assess how exactly script causes this difference, Chinese groups were recruited. Due to Chinese typography being complex enough to show similar results, and script directionality also being a factor, it provides a good comparison in order to assess how script creates an advantage in respect to visuospatial tasks for Arabic speakers. Also, in many artistic instances more artificial markers may be added to enhance artistic appeal. If the Chinese groups had outperformed on the Corsi Rotated similarly to the Arabic speakers the causative aspect of the script could be attributed to their shared features of directionality or typographical complexity, but since the Chinese groups did not show a similar effect, it may be the lenient structural rules of Arabic writing that creates a visuospatial advantage.

In the Corsi Forwards task, the Arabic monolinguals, Maltese/English bilinguals and the English monolinguals were outperformed by one or more of the Chinese groups. This is not surprising since the Chinese groups also had the highest scores on the Raven's task for general intelligence, with both the LP Chinese bilingual group and the monolingual Chinese group outperforming all four lifelong bilingual groups. The Corsi Forwards utilises working memory and, as many papers have shown, a strong correlation between working memory and general intelligence is most likely the reason why they outperform the other groups (Andrew et al., 2003; Colom et al., 2005). It should also be noted that the outperformance is not due to a bilingual advantage since although the HP Chinese bilinguals outperformed both the English and Arabic monolinguals, the Chinese monolinguals also outperformed the Maltese/English bilinguals. This general intelligence difference is not shown on the Corsi Backwards, although it should be noted that the lowest performing group, the Arabic monolinguals, were also the lowest on the Raven's task on general intelligence. Perhaps a reason no bilingual effects were found is, as many studies have stated, that mental abilities are highest in the student age group, which is why many studies find differences either in children or in elder participants. There was also no significant difference on any of the tasks due between the high proficiency and low proficiency Chinese bilinguals, which was expected since no bilingual effects were found.

As predicted, both Arabic speaking groups scored highest on the Corsi Rotated, with the Arabic/English bilinguals outperforming every other group. The Arabic monolinguals' scores, however, were not significant when compared with the Chinese monolinguals and the LP Chinese bilinguals. Again, this may be due to the Arabic monolinguals low performance on the Raven's task, which leads to low working memory as shown in their Corsi Backwards scores. As the Corsi Rotated also utilises components of working memory, the scores on the Corsi Backwards are controlled for in order to view the visuospatial effects more specifically. After controlling for working memory and looking at the participants' improvement from the Corsi Backwards to the Corsi Rotated, the Arabic monolinguals also outperformed all the other groups and show the same results as the Arabic/English bilinguals.

As mentioned above, the effect on visuospatial abilities found in Arabic speakers is most likely due to the lenient structural rules of Arabic writing, since the Arabic diacritic markers, although essential, are frequently misplaced in handwriting and calligraphy instances. This leads to Arabic readers adapting to complex visuospatial analysis when reading Arabic script. This specific Arabic reading complexity can also be mirrored in an example between Arabic and Maltese speakers. Although Maltese shares a large vocabulary with Arabic, many Maltese speakers comment that while Arabic speakers may understand some Maltese, they find it harder to understand Arabic. Again, this is due to Arabic language necessitating adaptability. Due to the many dialects of Arabic, many Arabic speakers do not find it unusual to hear an Arabic word spoken slightly differently, therefore upon hearing words such as cat (qattus in Maltese, قـــط /qut/ in Arabic) many Arabic speakers will infer the correct meaning. Furthermore, in order to read handwriting and other calligraphy-laden texts correctly, many Arabic speakers will have had to adapt to misplaced dots and diacritical markers from an early age, which in turn leads to further advantages outside the linguistic domain, specifically in visuospatial abilities. These results further indicate that effects may be language and task specific, regardless of bilingualism.

3.3.5 Summary

The previous experiment showed Arabic monolinguals and Arabic/English bilinguals outperforming English monolinguals and Maltese/English bilinguals on a visuospatial task: the Corsi Rotated. This led to the conclusion that the effects of Arabic speakers on visuospatial tasks are not related to a bilingualism or morphological complexity. The main difference between Arabic and Maltese is the script, and after seeing no similar effect in Maltese speakers an attempt was made to examine specific script characteristics that may have led to the visuospatial effects found. The addition of three Chinese groups (Chinese monolinguals, LP Chinese bilinguals and HP Chinese bilinguals) created a good comparison in terms of script. Like the Arabic writing system, Chinese script can be written from right-to-left and the Chinese script is also quite complex visually. Unlike Arabic, however, Chinese is rigid in its structure and placement, whereas Arabic handwriting and calligraphy often show a lack a uniformity in their dot and diacritic mark placement leading to higher degree of reliance on visuospatial abilities.

The results showed one or more of the Chinese groups outperforming the Arabic monolinguals, Maltese/English bilinguals and the English monolinguals. This was expected as the Chinese groups scored significantly higher on the general intelligence task. On the other hand, there were no significant differences in the Corsi Backwards results and no clear bilingual effects were found on any of the tasks. As predicted, the Arabic groups scored the highest on the Corsi Rotated, with the Arabic/English bilinguals outperforming all the other groups. The Arabic monolinguals significantly outperformed all non-Arabic speaking groups, except the Chinese monolinguals and the LP Chinese bilinguals. Since the Arabic monolinguals performed the least well on the Corsi Backwards, the underlying component of working memory shared by both the Corsi Backward and Corsi Rotated most likely explains the insignificant results especially after controlling for performance on the Corsi Backwards. The Arabic monolinguals show similar results to the Arabic bilinguals and outperform the other groups, except the Arabic bilinguals.

The mental rotation advantage found, which is most likely due to Arabic script's structural fluidity, shows that visuospatial reliance in the linguistic domain can be transferred to the non-linguistic domain. The results also reiterate that this is an Arabic language specific effect, and shows that executive control effects may be language and task specific as each language utilises such functions based on its own needs.

3.4 Experiment 3: Arabic Language Learners

3.4.1 Introduction

After finding that lifelong Arabic speakers exhibit an advantage in the Corsi Rotated, we investigated if this effect is evident in late Arabic learners. Students learning Arabic at the Islamic and Middle Eastern Studies Department at the University of Edinburgh were tested using the three Corsi Block Tapping Tasks. The late Arabic learners and their English monolingual comparisons are the same participants as those previously compared in Chapter 2, Experiment 2 (2.3.2). Since the students at the University of Edinburgh tended to outperform other university students on the general intelligence task, both groups were from the University of Edinburgh in order to control for general intelligence. Again, this difference on the timed Raven's could be due to the stronger selection criteria applied by the University of Edinburgh, as opposed to the previous universities that had been tested.

Initial hypotheses maintained that the Arabic students would outperform the English monolinguals on the Corsi Rotated similar to the Arabic participants. Bilingual effects were also predicted, as the participants learning Arabic may outperform on the Corsi Forwards and Backwards. As previously discussed however, due to the participants being university students they may be performing at the height of their cognitive functions, meaning that no bilingual effects would be present, as the previous chapter found no biliteracy or bilingual effects on executive control tasks related to inhibition and switching (2.3.4).

3.4.2 Methodology

Participants

Two groups were required for this study: monolingual English speakers and students learning Arabic (also detailed in section 2.3.2). All participants recruited were university students. The students learning Arabic were recruited from the Islamic and Middle Eastern Studies Department at the University of Edinburgh. The monolingual English speakers were also recruited from several schools within The College of Humanities and Social Science at the University of Edinburgh. The reason the University of Dundee students had been recruited in the previous studies was that the University of Edinburgh students outperformed on the general intelligence task. However as the bilingual group in this study was recruited from the University of Edinburgh, it was possible also to recruit the monolingual group from that same university without concern about disparity regarding general intelligence.

The participants were tested throughout the course of three years. Participants tested were in their first, second and fourth year of their undergraduate study. The number of Arabic learners was small and, although many students took Arabic in their first year as an elective, they rarely continued it as a major. Although the students usually spoke languages other than English and Arabic, recruitment was limited to participants who only knew the Latin script and were currently learning Arabic. A short summary of the participants' characteristics can be found in Table 3.5 and combined by group in Table 3.6.

	1st Year			2nd Year			4th Year		
	Sex	**Age**	**Ravens**	**Sex**	**Age**	**Ravens**	**Sex**	**Age**	**Ravens**
English monolinguals (UoE)	18F-4M	18.63	16.77	12F-5M	19.76	17.29	17F-7M	21.61	16.16
Arabic Language Learners	11F-11M	20.6	17.23	6F-5M	19.8	16.57	8F-3M	21.3	14.25

Table 3.5 [Study II, Experiment 3] Total number of participants with Mean for age and Raven's score.

	Combined Groups		
	Sex (Female-Male)	**Age (SD)**	**Ravens (SD)**
English monolinguals (UoE)	63 (47-16)	20.1 (1.5)	16.6 (4)
Arabic Language Learners	40 (21-19)	19.9 (1.5)	16.7 (3)

Table 3.6 [Study II, Experiment 3] Combined groups and total number of participants with Mean and SD (in parentheses) for age and Raven's score.

Apparatus and Procedure

The same apparatus used on the previous groups was used to control for general intelligence and language differences using the timed Raven's and a language questionnaire (2.2.2). The participants were tested on the Corsi Forwards, Backwards and Rotated tasks (3.2.2) during a one-hour testing process that also applied other executive control tasks for Study 1 (2.3).

3.4.3 Results

Analyses of Variance (ANOVAs) and independent t-tests were performed in order to compare mean differences between the groups. Analyses of variables not meeting the assumption of normality were conducted using non-parametric tests. Post hoc pairwise comparisons were carried out when appropriate. No significant difference was found between the groups regarding age or the Ravens general intelligence task (all $ps>.05$).

T-tests were used for comparing the English monolinguals ($n=63$) and the Arabic learners ($n=39$), after including participants from all three years (1, 2 and 4). They showed no significant difference between the English monolinguals and the participants learning Arabic on the Corsi Forwards ($t(38)=-1.5$, $p=0.1$) or the Corsi Backwards ($t(38)=.93$, $p=0.35$). The Arabic learners, however, significantly outperformed the English monolinguals on the Corsi Rotated task ($t(38)=-4.7$, $p<0.001$).

Next a comparison was performed on the groups based on years studying at university; either English monolinguals with a humanities subject or Arabic learners studying Arabic alongside the politics or history of the region. Year 1 comparisons also showed no difference between the English monolinguals ($n=19$) and the Arabic Learners ($n=21$) on the Corsi Forwards ($t(18)=-0.53$, $p>0.05$) or the Corsi Backwards ($t(18)=0.57$, $p>0.05$). As shown in the previous studies, however, Arabic learners significantly outperformed the English monolinguals on the Corsi Rotated even after only one year of study ($t(18)=-4.7$, $p<0.001$).

Due to the smaller group sizes in Year 2 and Year 4, the results were insignificant on any of the tasks, including the expected Corsi Rotated. In Year 2, the English monolinguals ($n=21$) and the Arabic learners ($n=11$) showed similar results on the Corsi Forwards ($t(10)=.71$, $p>0.05$) and the Corsi Backwards ($t(10)=0.82$, $p>0.05$). Although the Arabic learners performed better ($M=16.5$, $SD=5$) than the

English monolinguals (M=13.9, SD=3.4), the results were insignificant (t(10)=-1.66, p =0.1). Similar results were found in Year 4 with no significant difference between the English monolinguals (n=23) and Arabic learners (n=7) on the Corsi Forwards (t(6)=-0.46, p>0.05) and Corsi Backwards (t(6)=0.44, p>0.05). Again, in the Corsi Rotated, although it was insignificant (t(6)=-0.85, p>0.05), Arabic learners (M=17.6, SD=4.4) performed better than the English monolinguals (M=13, SD=3). Mean performance, standard deviation and significant differences on the Corsi tasks are presented in Table 3.7, and combined by group in Table 3.8.

	Corsi Forwards (SD) (out of 16)			Corsi Backwards (SD) (out of 16)			Corsi Rotated (SD) (out of 30)		
	1st Year	**2nd Year**	**4th Year**	**1st Year**	**2nd Year**	**4th Year**	**1st Year**	**2nd Year**	**4th Year**
English monolinguals	9.32 (1.9)	10.9 (11.4)	9 (1.6)	8.47 (2.3)	8.38 (1.8)	7.39 (2.1)	12.1 (2.3)	13.9 (3.4)	13 (3)
							p <.001		
Arabic Language Learners	9.62 (2.2)	9.73 (1.9)	9.43 (1.9)	8.24 (1.9)	7.91 (2.2)	8.29 (2.4)	17.3 (3.3)	16.5 (5)	17.6 (4.4)

Table 3.7 [Study II, Experiment 3] Mean and SD (in parentheses) on Corsi Block Tapping tasks

	Combined Groups			
	Corsi Forwards (SD)	**Corsi Backwards (SD)**	**Corsi Rotated (SD)**	
English monolinguals (UoE)	8.97 (1.72)	8.05 (2.1)	13 (3)	**p <.001**
Arabic Language Learners	9.62 (2)	8.15 (2)	17.2 (3.9)	

Table 3.8 [Study II, Experiment 3] Combined group's mean and SD (in parentheses) on Corsi Block Tapping tasks

This thesis confirms that all three Arabic speaking groups outperformed the other groups on the Corsi Rotated, once controlled for their performance on the Corsi Backwards (all ps< .001) F(7, 293) = 10.88, p < .001. The Arabic learners also show the same pattern found in the previous experiments, with the Arabic learners performing better on the Corsi Rotated than the Corsi Backwards, as early as their first year. Figure 3.10 visualizes the pattern found on the Corsi tasks in all 3 years tested. In order to better visually represent the trend in Corsi results, results are displayed in percentages.

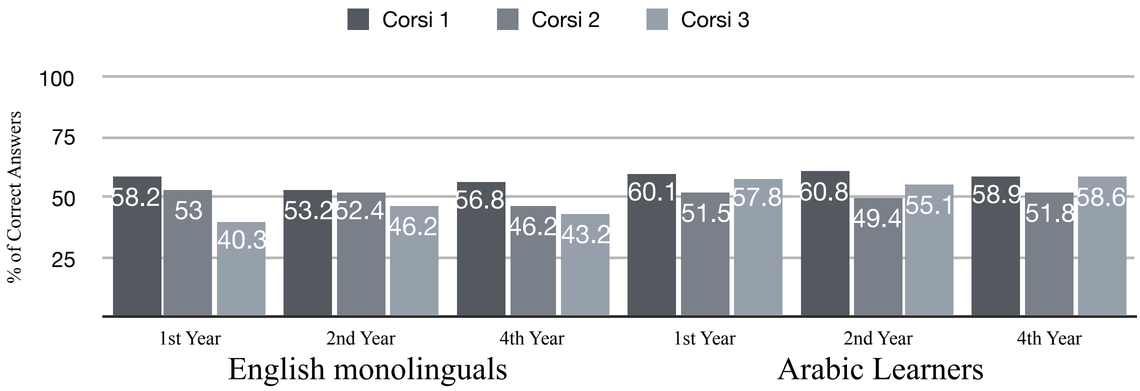

Figure 3.10 [Study II, Experiment 3] Patterns in Corsi Block Tapping Tasks

3.4.4 Discussion

After finding that lifelong Arabic speakers outperformed English, Maltese and Chinese speakers on the Corsi Rotated task, further research focused on whether participants learning Arabic at a later stage in life would show similar results as lifelong bilinguals. Students studying Arabic at the University of Edinburgh were tested during their university years. As there were a limited number of students learning Arabic, which decreased every year, due to students taking Arabic as an elective for their first year only, recruitment was done twice a year for three years. Monolingual English speakers were recruited from the University of Edinburgh so that both groups would be from the same university.

Results showed that when analysed both as a group, or based on years of study, the Arabic learners and the English monolinguals do not differ significantly on the working memory tasks, while showing similar performances on the Corsi Forwards and the Corsi Backwards. No bilingual effects can therefore be seen between the Arabic learners and the English monolinguals, which may be due to university-aged students performing at the height of their mental abilities. Studies done on children and older adults are more likely to show effects on such tasks.

On the Corsi Rotated, however, the results revealed the same effect as found previously: the Arabic Learners significantly outperformed the English monolinguals on the visuospatial task. After comparing the participants based on the years spent studying the language, results showed that participants studying Arabic for at least one year showed these advantages in the visuospatial field. This confirms that it is the script that is influential since the alphabet is one of the first things to master upon learning a new language. Although it is insignificant due to small group sizes, both the second and fourth years performed much better than the English monolinguals on the Corsi Rotated and showed a similar pattern to the Arabic tested groups performing better on the Corsi Rotated than on the Corsi Backwards.

Had the results on the Corsi Rotated been found without testing Arabic monolinguals, they may have mistakenly been attributed to bilingual effects. This study, however, shows that effects found in research attributed to bilingual effects may in fact be language specific and therefore greater consideration needs to be given to language and task-specific results. This may help clarify the inconsistencies found in research on bilingual effects outside the linguistic domain.

3.4.5 Summary

In order to see whether participants learning Arabic at a later stage in life would show similar results an attempt was made to replicate the previous Corsi Block-Tapping task experiment with students at the University of Edinburgh who were learning Arabic. After comparing them with English monolinguals, also from the University of Edinburgh, results showed the same pattern found in previous experiments. Although no bilingual effects were found in the Corsi Forwards and Corsi Backwards this may be due to students being at the height of their cognitive abilities, as discussed in 2.3.4.

The results reiterated that the Arabic speaking students outperformed the English monolinguals on the Corsi Rotated, with the advantage showing as early as the first year of study. This visuospatial advantage seems to be unique to Arabic and shows that executive control results may be language and task specific.

3.5 Study II Conclusion

The main objective of this thesis is to observe cognitive differences due to biliteracy on three specific aspects: executive control, visuospatial abilities and morphological complexity processing. In the first study the focus was on biliteracy effects on executive control tasks related to inhibition and switching (Chapter 2). This chapter then studied the effects of biliteracy and script on visuospatial abilities, specifically mental rotation. While previous research has shown that bilinguals outperform on visuospatial tasks (1.2), this study examined whether bilinguals with more than one script outperform bilinguals with languages that share a script. The results indicated that Arabic speakers, regardless of bilingualism, showed a mental rotation advantage. This suggests that the effects were not due to knowledge of more than one script per se, but to effects specific to the Arabic script itself. The study concludes that regardless of bilingualism, script has significant effects on mental rotation.

In the first experiment, a comparison was performed done on English monolinguals, Arabic monolinguals, Maltese/English bilinguals and Arabic/English bilinguals utilising three versions of the Corsi Block-Tapping tasks: Corsi Forwards, Backwards and Rotated. Due to Maltese and Arabic being very similar in characteristics such as morphology and vocabulary, the main difference is that Maltese is the only Semitic language to be written in the Latin script, while Arabic utilises its own. This creates a good comparison for investigating how biliteracy affects executive control. The results showed that while all the groups performed similarly on the Corsi Forwards and Corsi Backwards, the Arabic monolinguals and the Arabic bilinguals outperformed on the Corsi Rotated. It was found that, unlike the

English monolinguals and the Maltese/English bilinguals, whose performance worsened with each task, the Arabic speaking groups showed better results on the Corsi Rotated than the Corsi Backwards. This visuospatial advantage is clearly not due to bilingual effects since the Maltese bilinguals do not show the same results, whereas the Arabic monolinguals do. The effect is most likely related to script as that is the main difference between Maltese and Arabic.

The second experiment distinguished how script led to the visuospatial effect evidenced in the Arabic speakers, by adding another language group, namely, Chinese speakers. Chinese was chosen due to its intricate script and that it shares a right-to-left writing direction with Arabic. Unlike Arabic, however, where handwritten and calligraphic scripts often misplace dots and diacritic marks, Chinese is consistent in its structure and placement of markers. After testing the same Corsi tasks the results showed that on the Corsi Forwards the English monolinguals, Arabic monolinguals and Maltese/English bilinguals were outperformed by one or more of the Chinese groups. This, however, is probably due to the Chinese groups scoring higher on the Raven's general intelligence task. A similar pattern showed Arabic speakers achieving higher results than all the other groups on the Corsi Rotated. The Arabic bilinguals significantly outperformed all other groups on the Corsi Rotated. Whereas on initial analysis the Arabic monolinguals outperformed all groups except the Chinese monolinguals and the Chinese LP bilinguals, again this is due to their low performance on the Corsi Backwards, since, after considering their performance on the Corsi Backwards, the Arabic monolinguals also significantly outperformed all other groups. After not seeing a similar visuospatial effect in the Chinese speakers to of the Arabic speakers, it was concluded that the Arabic script's structural fluidity is the most likely influence rather than directionality or visual complexity.

The third experiment investigated whether these visuospatial results would show in late Arabic language learners studying Arabic at the university. English monolinguals and students learning Arabic, (both from the University of Edinburgh) were compared, again utilising the Corsi Block Tapping Tasks. The results showed no differences in general intelligence, Corsi Forwards, or Backwards. On the Corsi Rotated, however, the Arabic learners in all three years showed better results on the Corsi Rotated than on the Corsi Backwards. Furthermore, the results showed the Arabic learners' group significantly outperformed the English monolinguals on the Corsi Rotated, with significance even after only one year of language learning. This shows that this non-linguistic visuospatial advantage found in Arabic speakers can be replicated even in late language learners and, indeed, after only one year of learning Arabic.

This study has clearly shown that all three Arabic speaking groups (i.e, Arabic monolinguals, lifelong Arabic/English bilinguals and the late Arabic bilinguals) outperformed all other language groups on the Corsi Rotated. The Arabic speakers all show the same pattern of performing better on the Corsi Rotated than the Corsi Backwards. These results confirm that language effects, even outside of the linguistic domain, may be language and task specific. As each language utilises different components of executive control in their processing, task results will reflect these unique needs. Future research will need to take this into consideration and compare bilinguals, not only to one group of monolinguals, but to monolinguals of both languages. As more languages are tested using these methods and tasks, further insights will be gleaned as to the exact qualities languages require in order to produce such effects. Clinical research may also explore potential benefits of teaching Arabic to individuals with visuospatial disadvantages, as this may provide an alternative way of dealing with specific executive control differences.

Chapter 4
Study III: Effects of Biliteracy on Hemispheric Variance

4.1 Study III Introduction

As shown in the previous two studies on executive control and mental rotations, the unique characteristics of languages, such as their script, may lead to specific effects on cognitive functions. This thesis continues to explore the effects of biliteracy, specifically on cognitive functions, with this third and final study examining hemispheric variance in distinguishing morphological markers. Eviatar and Ibrahim (2007) suggested that Semitic languages employ both hemispheres of the brain when distinguishing morphological markers, whereas English speakers employ only the left hemisphere. Morphological markers in both Hebrew and Arabic are complex, as they are usually embedded within words, compared to English markers such as the plural 's'. Both Hebrew and Arabic are also written from right to left, a characteristic which may lead to hemispheric variance in language processing. Maltese, however, shares the complexity of the Arabic morphological markers, while written from left to right. Arabic and Maltese morphology has previously been detailed in Chapter 1 (1.1). Comparing English, Maltese and Arabic speakers will help ascertain if the results found by Eviatar and Ibrahim (2007), were because of script directionality or complex morphology.

4.2 Experiment

4.2.1 Introduction

Inspired by the Eviatar and Ibrahim (2007) study detailed in 1.4, the question arose as to the influence of biliteracy, and specifically script directionality, on hemispheric variance. The language groups chosen will help ascertain if the results found in the Israeli & Eviatar (2007) study are due to script directionality or morphological complexity. The tasks used in this thesis contain the same words used by Eviatar and Ibrahim (2007).

The same criteria were employed for this thesis. The groups consisted of English monolinguals, Arabic monolinguals, Maltese/English bilinguals, and Arabic/ English bilinguals. A visual lexical decision task was applied in all three languages: English, Maltese, and Arabic. Bilinguals completed two versions of the task, one in each of their respective languages. An auditory version of the task was also used in this experiment: Participants would hear the sounds either from the left or right headphone and would determine whether the sound was a word or non-word. Although the auditory cortex is not as distinctly split as the visual field, it is closer to the bilingual experience and may provide further insight to hemispheric differences between the three language groups. Response time and accuracy determined the results. The comparison between the four groups will help determine whether the previous results are linked to the directionality of the script; and the bilingual groups will further address whether the effects of one language are transferred to the other.

Initial hypotheses maintained that the research findings would comport with the Israeli & Eviatar (2007) study and that both Semitic groups would show bilateral hemispheric processing compared to the English monolinguals who would rely only on the left hemisphere when distinguishing morphological markers. It was also hypothesized that the Maltese speakers may show a preference for the left hemisphere due to the directionality of the Maltese script. Similar responses were anticipated in both the visual and auditory lexical decision task.

4.2.2 Methodology

Participants

This study utilised the same participants as in the first and second study (2.2.2), i.e., monolingual English speakers, Maltese/English bilinguals, Arabic/English bilinguals and Arabic monolinguals.

Apparatus and Procedure

This thesis used both a visual and an auditory version of a lexical decision task (LDT). The visual task was based on the same one used by Eviatar and Ibrahim (2007), with an additional auditory version added. All three experiments were created using E-prime software. The sound manipulation in the audio version, i.e., the splitting and addition of white noise, was done using Audacity (version 2.1.1). The equipment used was a 13-inch MacBook Pro with Retina display, and Sony MDR-ZX310 headphones with a 10–24,000Hz frequency range. The volume was left at 50% but participants were encouraged to adjust to their comfort level.

Since the groups were the same as the ones used for the first two studies the procedure was administered after completion of the tasks for studies I and II for the four shared groups. The entire session took 75 minutes for each participant. The participants began with a short practice trial of the visual lexical decision task, and after successful completion, began with the visual lexical decision task before finally completing the auditory version of the task.

In this study any processing from the right visual field or right auditory pathway is attributed to the left hemisphere and vice versa, as the eyes and ears cross hemispheres. The analysis investigated the response time and accuracy based on the side of the screen or the headphone the word was received from.

Visual Lexical Decision Task

In a lexical decision task (Meyer & Schvaneveldt, 1971) participants must decide whether a series of letters on the screen represents an actual word or not. The stimuli, in black, are presented on a white screen, either to the left or right side. A fixation point is present between the trials. As in the Eviatar and Ibrahim (2007) study, the ‘up’ and ‘down’ arrows were used to indict ‘yes’ and ‘no’ respectively. Three versions of the task were made: an English version, an Arabic version and a Maltese version. The English and Arabic words were similar to the words used in the Eviatar and Ibrahim, (2007) study, as some needed to be changed in order to control for cognates. While cognates could not be eliminated completely, they were controlled for, since each language has 30% cognates of the other languages. Any new English and Arabic words, as well as the Maltese words, were chosen to follow specifications similar to the ones used in Eviatar and Ibrahim, (2007) study (detailed below). Forty words and 40 non-words were included in the test, each with both a left and right version. The test would randomly assign 80 stimuli to each participant either to the left or right side of the screen. Of the 80 words or non-words, 20 were morphologically complex and 20 were morphologically simple. For Arabic, Eviatar and Ibrahim (2007) judged morphologically complex words by looking at the root of the word. Words with roots that appear only in that form were considered simple whereas transformed roots were considered complex. Maltese words were chosen following the same specifications as Arabic, as it shares a similar morphology. For English words, meanwhile, derivations were considered morphologically complex. For example, in English, ‘actor’ was considered complex while ‘ocean’ was assessed as a simple word.

The complete list of English, Maltese and Arabic words can be found in Appendix A.3.

Auditory Lexical Decision Task

The auditory version of the LDT followed the same concept as the visual LDT. However in the auditory LDT the participants heard the sounds out of either the right or left headphones instead of seeing them. The English and Arabic words were spoken by an adult female who is a native speaker of both English and Arabic, and the Maltese words were spoken by an adult male native speaker of Maltese. The sounds were recorded using a microphone on a 13-inch MacBook Pro. The words and non-words were later split into left- and right-side sounds, and constant white noise was added to the other side, so the participants would hear a word/non-word in one ear and white noise in the other. The program Audacity 2.1.1 was used for audio editing.

4.2.3 Results

Visual Lexical Decision Task

English

Simple Words. The accuracy and response time in respect to simple words in English showed no significant difference between any of the groups and showed no hemispheric preference (all ps$>$ .05).

Complex Words. A significant group effect was found regarding the accuracy on the visual Lexical Decision Task (Complex Words) between the English monolinguals, Arabic bilinguals and Maltese bilinguals in both the right visual field ($H(2) = 23.4$, $p < .001$) and the left visual field ($H(2) = 20.9$, $p < .001$). The Arabic bilinguals were significantly less accurate at identifying words than the English monolinguals and the Maltese bilinguals (all ps$<$ .001). No effect was found pertaining to the accuracy between the left and right visual field in English (complex words) in all three English speaking groups (all ps$>$ .05). No group effect was found in the response time of the visual Lexical Decision Task (complex words) in either the right ($H(2) = 3.5$, $p = .1$) or left visual field ($H(2) = 2.65$, $p = .2$). In English (complex words) no effect was found regarding the response time between the left and right visual fields in all three English speaking groups (all ps$>$ .05). Accuracy mean performance and standard deviation in both the right and left visual field are presented in Figure 4.1.

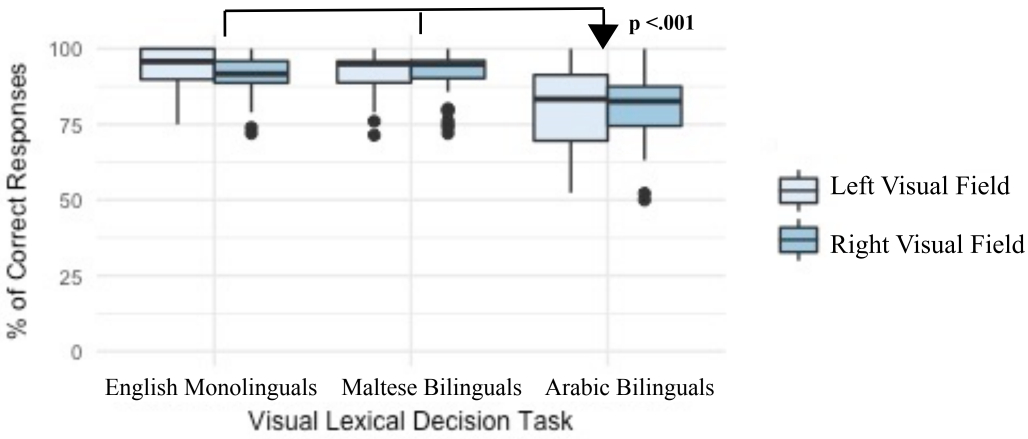

Figure 4.1 [Study III] Mean and SD for Accuracy on the Visual Lexical Decision Task: English Complex Words

Arabic

Simple Words. Accuracy and response time for the simple words in Arabic showed no significant difference between the Arabic monolinguals and the Arabic/English bilinguals, and no hemispheric preference was found within the groups (all ps> .05).

Complex Words. In both groups, no effect was found regarding the accuracy or response time between the left and right visual fields for Arabic complex words (all ps> .05).

Maltese

Simple Words. Accuracy and response time for simple words in Maltese showed no significant hemispheric preference in the Maltese/English bilinguals.

Complex Words. No effect was found regarding the accuracy or response time between the left and right visual fields for Maltese complex words (all ps> .05)

Auditory Lexical Decision Task

English

Simple Words. Accuracy and response time for simple words in English showed no significant difference between any of the groups and showed no hemispheric preference (all ps> .05).

Complex Words. A significant group effect was found in the audio Lexical Decision Task (complex words) between the English monolinguals, Arabic bilinguals and Maltese bilinguals in both the right ($H(2) = 17.9$, $p< .001$) and left ear ($H(2) = 7.7$, $p= .02$). In the right ear, both the Arabic and Maltese bilinguals were significantly less accurate at identifying words than the English monolinguals, while the Maltese bilinguals outperformed the Arabic bilinguals (all ps< .05). Upon hearing the words from the left ear, however, only the Arabic bilinguals were significantly less accurate than the English monolinguals ($p=.02$). No group effect was found in the response time pertaining to the auditory Lexical Decision Task (complex words) in either the right ($F(2, 109) = 1.114$, $p=.3$) or left auditory cortex ($F(2, 109) = 0.484$, $p=.6$). Accuracy mean performance and standard deviation in both the right and left auditory cortex are presented in Figure 4.2.

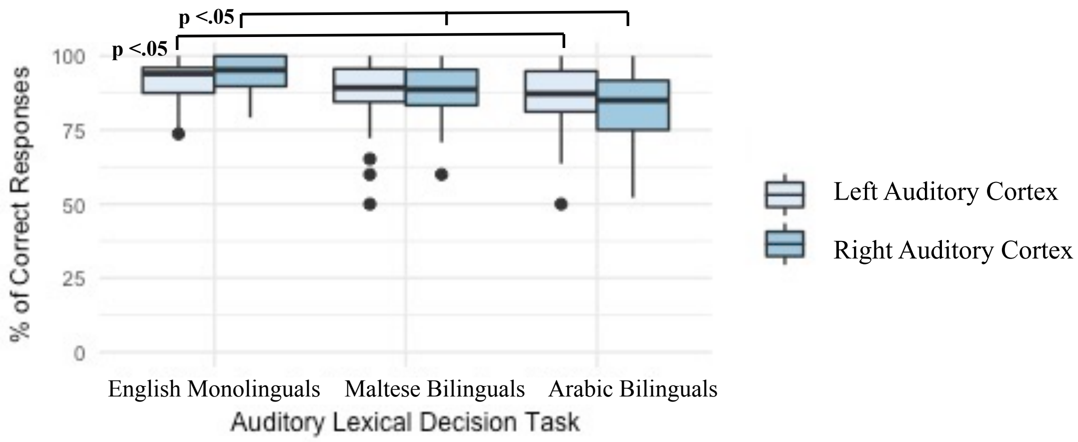

Figure 4.2 [Study III] Mean and SD for Accuracy on the Auditory Lexical Decision Task: English Complex Words

No effect was found regarding the accuracy within the groups between the left and right auditory cortex for English complex words in all three English speaking groups (all ps> .05). All three English speaking groups, however, were significantly faster when complex English words were heard from the right ear then from the left (by an average of 26.6 ms); (all ps< .05), thereby showing a left hemisphere advantage in English. Response time mean performance, and standard deviation in both the right and left auditory cortex is summarised in Table 4.1 and presented in Figure 4.3. A detailed view of the English monolinguals response time on the individual words is presented in Figure 4.4.

	Response Time in ms		
	Right Auditory Cortex (SD)		**Left Auditory Cortex (SD)**
English monolinguals (UoD)	1115 (134)	p <.05	1150 (122)
Maltese/English bilinguals	1151 (121)	p <.05	1172 (118)
Arabic/English bilinguals	1153 (110)	p <.05	1177 (125)

Table 4.1 [Study III] Mean and SD (in parentheses) for Response Time on the Auditory Lexical Decision Task: English Complex Words

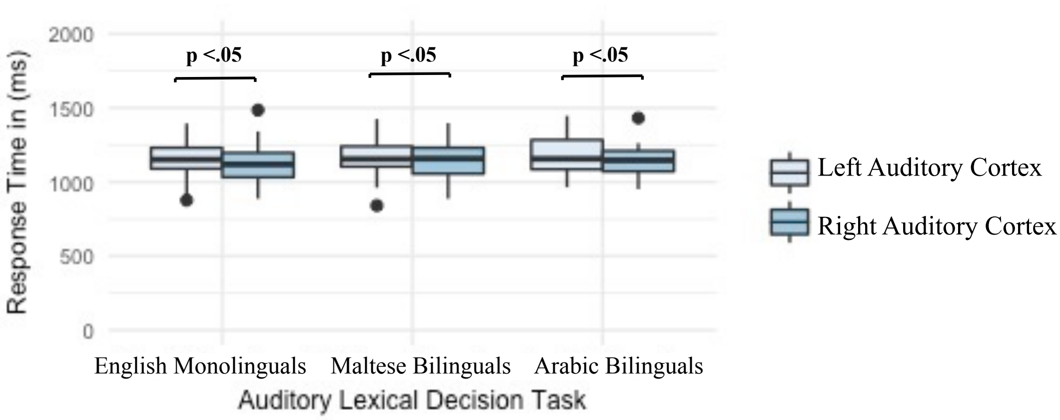

Figure 4.3 [Study III] Mean and SD for Response Time on the Auditory Lexical Decision Task: English Complex Words

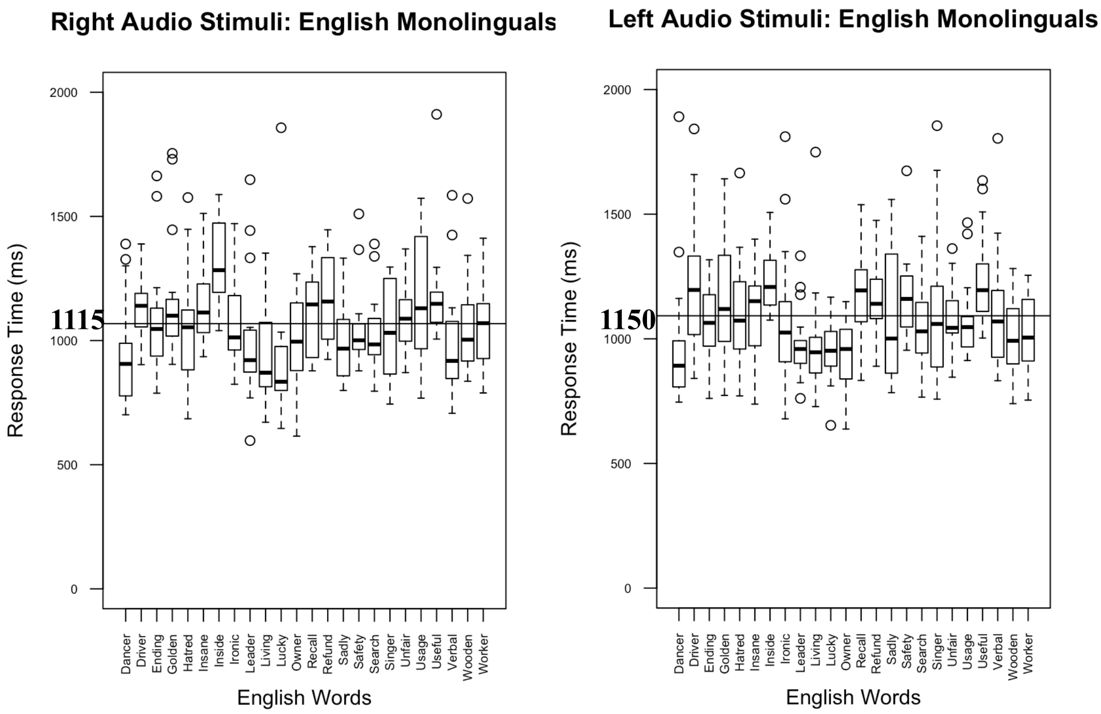

Figure 4.4 [Study III] Stimuli mean for Response Time on the Auditory Lexical Decision Task: English Complex Words

Arabic

Simple Words. Accuracy and response time regarding simple words in Arabic showed no significant difference between the Arabic monolinguals and the Arabic/ English bilinguals, and no hemispheric preference was found within the groups (all ps> .05).

Complex Words. No effect was found pertaining to the accuracy or response time between the two Arabic groups, or between the left and right auditory cortex within the groups, indicating no significant hemispheric preference (all ps> .05).

Maltese

Simple Words. Accuracy and response time regarding simple words in Maltese showed no significant hemispheric preference in the Maltese/English bilinguals.

Complex Words. No effect was found in the accuracy or response time between the left and right auditory cortex in Maltese (all ps> .05).

4.2.4 Discussion

Influenced by the Eviatar and Ibrahim (2007) study, this thesis used visual and auditory LDTs to compare monolingual English speakers, English/ Maltese bilinguals, English/Arabic bilinguals and Arabic monolinguals. Three versions of the visual and auditory LDT were used: English, Arabic and Maltese. This thesis investigated whether hemispheric differences found between the languages in previous studies were due to morphological judgment or influenced by script directionality. Since Arabic and Maltese share morphological characteristics but differ regarding their script offers a unique opportunity to explore script's influence on hemispheric word processing in Arabic, English and Maltese. Unlike previous research, an auditory LDT task was added where participants heard the words instead of reading them. Hearing a spoken language is perhaps closer to the bilingual experience. The results will also determine if one language's hemispheric preference influences the hemispheric preference in respect to the other language in bilinguals.

As hypothesized and shown in previous research, the results showed no significant differences in response time or accuracy when comparing the groups' results in both seeing or hearing simple words, either in English, Arabic or Maltese. Simple words in all three languages show no hemispheric preference and all groups were accurate in assessing the simple words and non-words.

However, the analysis of complex word processing showed significant differences. In the visual LDT in English, the Arabic/English bilingual group was the least accurate in successfully identifying English words, compared to the English monolinguals and the English/Maltese bilinguals. However, there was no difference in response time between the three groups. Although all groups are lifelong bilinguals, perhaps because English is not an official language in Saudi Arabia, unlike in Malta and the UK, the Arabic/English bilinguals were slightly less accurate due to a lower level of English performance under a time limit. It is likely, however, that the bilingual groups may in general be slightly inaccurate due to time limit pressure, since the Maltese bilinguals were also significantly slower in the auditory LDT. Previous research has shown bilinguals performing more slowly than monolingual's lexical tasks due to the competition between their languages (Roberts, Garcia, Desrochers, Hernandez, 2002; Rogers et al., 2006). The results of this thesis demonstrated, however, that there was no difference between any of the group's hemispheric processing since, unlike previous results, they did not show a left hemispheric preference in English in the visual LDT. No hemispheric preference was found in the hemispheric processing of complex words in either the Arabic groups or the Maltese/ English bilinguals.

Results on complex word processing in the auditory LDT showed that both the Arabic/English bilinguals and the Maltese/English bilinguals were again less accurate in identifying complex English words than the English monolinguals; however the groups' response times were similar. Although no accuracy effect was found between hemispheres in the groups, all three groups showed a left hemisphere advantage. All three English speaking groups were significantly faster when complex English words were heard from the right ear than heard from the left, by an average of 23.1 ms. This result is similar to the results found by previous researchers using the visual LDT. The participants in the Semitic language groups, on the other hand, showed no preference for either hemisphere and utilised both similarly. This also applies to the bilingual groups, Arabic/ English and Maltese/English, showing that hemispheric preference does not transfer to other languages in bilinguals, since they showed a left hemispheric preference in English but not in Arabic or Maltese. No difference was found between the Arabic monolinguals or the Arabic/English bilinguals regarding any Arabic words.

Morphological complexity in Semitic languages may contribute to the Semitic languages' utilisation of both hemispheres when processing complex words. The simple morphology of English words, such as the end additions of plural 's' or past 'ed' words, when compared to Arabic and Maltese deconstruction of root words in order to add plurals and tenses, may be analysed without the need to rely on both hemispheres.

These findings emphasize that results may be both task and language specific. Languages have unique attributes that distinguish them in respect to tasks, attributes that may sometimes not transfer to other languages. Bilinguals, therefore, cannot be seen as one homogenous group and should be distinguished not only by their proficiency but by the languages themselves.

4.3 Study III Conclusion

A comparison was undertaken between English monolinguals, Arabic monolinguals, Arabic/English bilinguals and Maltese/English bilinguals using a Lexical Decision Task in both visual and auditory form. The tasks recorded their accuracy and response time regarding their ability to correctly identify simple and complex words. Six versions of the task were done in English, Arabic and Maltese, with each language having a visual and auditory version. The bilinguals performed the task in both English and their respective language.

The results showed no difference between any of the groups regarding any of the simple words in any of the languages, since they utilised both hemispheres equally. Complex words showed no preference in the visual LDT; however in the auditory LDT, results reiterate what was found in the visual LDT study of Eviatar and Ibrahim (2007): all English-speaking groups were significantly faster when complex English words were heard from the right ear than heard from the left. No preference was evident in either the Arabic or Maltese groups; thus finding that hemispheric preference was not due to script. The English monolinguals, the English/ Maltese bilinguals and the English/Arabic bilinguals, favoured the left hemisphere when processing complex words heard in English. The English/Maltese bilinguals used both hemispheres for Maltese and the same was found for Arabic in both the Arabic monolinguals and the English/Arabic bilinguals. The results reiterate that this is likely due to the morphological complexity of Arabic and Maltese compared to English. Finally, the results indicate that the hemispheric preference of one language does not transfer to other languages in bilinguals since the bilinguals showed different processing for English than Arabic and Maltese.

Further research could usefully compare languages with complex morphology to try to distinguish what exactly leads to these different results when using both the visual and auditory LDT. Further comparisons of bilinguals would also benefit from more precise hemispheric analysis, such as EEG comparisons.

Chapter 5: Conclusions

5.1 Discussion

The objective of this thesis was to examine the effects of biliteracy on three significant aspects of cognitive functions: executive control, visuospatial abilities, and hemispheric variance in morphological processing. The three languages (English, Maltese and Arabic) when compared are suited to reveal specific script effects. Due to the shared characteristics between Maltese and Arabic, the languages are expected to show similar effects, however these two languages differ in one key aspect: their scripts. While Maltese, like English, utilises the Latin script, Arabic uses the Arabic script, written from right to left. The characteristics of all three languages are detailed in 1.1. Comparisons between the three groups were used to examine differences in cognitive functions due to biliteracy. While previous research has shown bilinguals outperforming on tasks related to cognitive functions, specifically those on executive control and visuospatial abilities, it had not previously looked at script effects. The relationship between bilingualism and executive control was examined in Section 1.2. It is suggested that the process of acquiring a different writing system may lead to unique effects on cognitive functions. The results of the studies, however, revealed unique language-specific effects leading to a discussion on linguistic diversity and whether the different characteristics of languages may lead to differing results in cognitive function tasks. Further questions rose: do languages themselves exhibit different results, and do different language combinations lead to unique effects on cognitive functions? A final study examined whether script influences different usage of the two brain hemispheres among English, Maltese, and Arabic speakers given the task of distinguishing morphological markers. After conducting the three experimental studies, the research questions detailed in the beginning of the thesis can now be answered:

1. What are the main effects of biliteracy on executive control in both lifelong and late bilinguals? (study I)
2. Does script influence mental rotation independently of bilingualism? (study II)
3. Is the hemispheric variance in distinguishing morphological markers found in previous research on Semitic languages influenced by script? (study III)

The first study, "Effects of Biliteracies on the Executive Control of Lifelong Bilinguals and Language Learners", investigated the effects of biliteracy on executive control in both lifelong and late bilinguals (chapter 2). The results of Study I revealed that biliteracy has no distinct effects on executive control tasks related to inhibition and switching, in either lifelong bilinguals nor language learners. Two experiments were done in order to answer this question. Both compared the groups on the executive control tasks, AX-CPT and the TEA, while attempting to control for general intelligence, socio-economic status and language history. The first experiment looked at lifelong bilingual groups, those who have learnt and constantly used their languages before the age of eight. The experiment on lifelong bilinguals compared English monolinguals, Arabic monolinguals, Maltese/English bilinguals, and Arabic/English bilinguals on the executive control tasks which focused on inhibition and switching. The results found no difference between any of the groups on the inhibition tasks of the TEA 'Elevator Task with Distraction'. On the second TEA task, the 'Elevator Task with Switching', the Maltese/English bilinguals outperformed the Arabic monolinguals. It was determined, however, that this was not a product of bilingual effects since the Arabic monolinguals were also outperformed by the English monolinguals. An explanation was that the results were due to the Arabic monolinguals having the lowest scores on the general intelligence task as well as a lower reported socio-economic status.

No bilingual effects were found on the AX-CPT either. Although both Arabic groups were less accurate on the target trial 'AX' than the other groups, this did not affect their accuracy in the other trials. Since both Arabic groups were significantly less accurate on the 'AX' trial, the results could be an effect of the different Arabic writing system. The accuracy of the Arabic speakers suffers as they attempted to respond rapidly to a task in another writing system. In the control trial 'BY', the English monolinguals were significantly faster than the other groups; however, again this did not affect the other trials designed to differentiate between reactive and proactive control. The 'BY' trial results were consistent with the research showing that monolingual speakers respond more quickly than bilingual speakers in linguistic tasks. The participants may have processed the task as a linguistic task, due to the cues involving Latin alphabets. Therefore, the English monolinguals' faster response time coincides with previous research showing bilinguals slower response time on linguistic tasks (Costa & Santesteban, 2004; Gollan et al., 2005).

The second experiment in the study focused on late language learners and compared students learning Arabic to students learning a morphologically complex language written in the Latin script, as well as monolingual English students. The three groups were tested using the same executive control tasks, AX-CPT and the TEA, but no differences were found between any of the groups. Overall, the first study found no biliteracy effects, nor even bilingual effects. The results however are common in this age group as previous research has argued that since components of executive control are at their highest in this age group, no bilingual effects will be found.

The second study "Effects of Arabic on Mental Rotation", questioned whether script influences mental rotation, independent of bilingualism. The results of the three experiments administered in Study II revealed that indeed, certain scripts, specifically Arabic, show a unique advantage in mental rotation, regardless of bilingualism. The three experiments administered three versions of the Corsi Block tapping task: the Forwards, Backwards and Rotated Version. The first experiment compared English monolinguals, Arabic monolinguals, Maltese/English bilinguals, and Arabic/English bilinguals. These groups were chosen in order to assess the effects of biliteracy on mental rotation. The results showed that while there was no difference between the groups on the Corsi Forwards or the Corsi Backwards, both Arabic-speaking groups outperformed the English monolinguals and the Maltese/ English bilinguals on the Corsi Rotated task. The data showed that while the performance of the English monolinguals and the Maltese/English bilinguals worsened as the tasks progressed from the Corsi Forwards to the Corsi Backwards, and then to the Corsi Rotated, the Arabic monolinguals and the Arabic/English bilinguals performed better on the Corsi Rotated than on the Corsi Backwards. The results showed that this Arabic effect on mental rotation is not an effect of bilingualism, since Arabic monolinguals showed the same results; neither is it due to the morphological complexity of Arabic, since Maltese is also a morphologically complex language.

The results were unique to the Arabic script; therefore further examination required another complex script in order to replicate similar effects. The second experiment added Chinese monolinguals, Chinese low proficiency bilinguals, and Chinese high proficiency bilinguals. The addition of Chinese would help determine if script directionality caused the effects. This is because while English and Maltese use the Latin script written from left to right, Arabic utilises its own script written from right to left. Chinese, however, can be written both horizontally and vertically, and in both directions. The results showed that, despite the Chinese groups having a higher general intelligence score and hence some outperformance on the Corsi Forwards test, Arabic speakers still showed a significantly larger effect on the Corsi Rotated than all other groups, especially after controlling for the results on the Corsi Backwards. Similar to the first experiment, the results showed that, while the performance of all other groups was worse on the Corsi Rotated than the Corsi Backwards, both Arabic-speaking groups performed better. The addition of the Chinese speakers showed that the results were not due to the script directionality or the typographical complexity of the script since the Chinese writing system is also complex. Chinese speakers did not outperform on the Corsi Rotated test as observed with the Arabic speakers. Instead, the results could be attributed to the Chinese writing system being more structural than the Arabic writing system. Chinese is rigid in its writing structure, whereas Arabic often shows a lack of uniformity in its dot and diacritic mark placement, specifically in handwriting and calligraphy. This leads to a need for stronger visuospatial abilities in Arabic.

The third experiment attempted to identify the degree of Arabic proficiency needed for the results to show an effect on mental rotation. Using the same tasks, a comparison was made between English monolinguals studying at the University of Edinburgh and students studying Arabic at the same university. The students were compared from their first year of study to their final (fourth) year of study, excluding their third year when they were studying abroad. The results showed that while there was again no bilingual effects found for the Corsi Forwards and Corsi Backwards, the Arabic learners were more accurate in the Corsi Rotated, even after only one year of Arabic study. This indicates that the mental rotation effect found in Arabic speakers is evident even in low proficiency speakers and is most likely due to script, since the Arabic alphabet is one of the first things taught when learning Arabic. The mental rotation effects found in Arabic speakers suggest that different languages show different effects and that linguistic diversity needs to take a bigger role in research. For example, had the Arabic/English bilinguals been compared only to monolingual English speakers, the results could have mistakenly been attributed to bilingual effects.

Thus, Experiment 1 showed that the unique results were not due to bilingualism since they were apparent even in the monolingual Arabic speakers. Experiment two, meanwhile, indicated that the results were not affected by script directionality, since the Chinese speakers did not show similar results. This led to the conclusion that Arabic's complex script affected mental rotation. Finally experiment three showed that the results were apparent even in first-year Arabic learners. The three experiments in study II conclude that Arabic has unique attributes that show its speakers outperforming other groups on visuospatial abilities

The third and final study, "Effects of Biliteracy on Hemispheric Variance", is based on a study done by Eviatar and Ibrahim (2007). They compared Arabic, Hebrew, and English speakers on a visual lexical decision task and found that Semitic languages, such as Hebrew and Arabic, utilise both hemispheres when distinguishing morphological markers, whereas English speakers showed a left hemispheric preference. This thesis investigated if the results of the Ibrahim (2007) study were influenced by script directionality or morphological complexity. The results of Study III revealed that the hemispheric variance in distinguishing morphological markers found in Semitic languages was not influenced by script directionality but was rather a result of complex morphology. The experiment utilised the four groups used in the previous studies: English monolinguals, Arabic monolinguals, Maltese/English bilinguals, and Arabic/English bilinguals. In addition to comparing the groups by means of a visual lexical decision task as the original study had done, this thesis also used an auditory lexical decision task. Both tasks were done in either English, Maltese or Arabic speakers, with bilinguals doing the task in two languages. While the groups did not show any significant differences in the visual LDT, they did show similar results as the Eviatar and Ibrahim (2007) study in the auditory LDT. The Semitic languages, Maltese and Arabic, showed no hemispheric preference in Arabic and Maltese, whereas all three groups showed a left hemispheric preference in English. The results thereby showed that hemispheric preference was not due to script and is most likely due to the embedded morphology and complexity in Arabic and Maltese as opposed to English. The results also showed that the hemispheric preference is non-transferable in bilinguals. While the bilinguals showed a preference in English, they did not show a hemispheric preference in their other Semitic language. The results, therefore, support the literature: that languages are different, and that linguistic diversity may cause speakers to exhibit different effects on executive control tasks.

Overall, all three studies examined whether linguistic distance and language differences significantly affect a bilingual's cognitive functions. This thesis found no significant differences between the Maltese/English bilinguals and the Arabic/ English bilinguals attributed to biliteracy. The first study compared the groups on the executive control tasks of inhibition and switching, and found no differences. This suggests that there are no biliteracy effects on executive control tasks. No biliteracy effects were found in the second study either, as the results were specific to Arabic speakers, regardless of being bilingual or monolingual. Therefore, any differences found between the groups were not due to biliteracy. In the final study, biliteracy's influence on hemispheric variance was examined and the results indicated that both the Maltese/English bilinguals and the Arabic/English bilinguals performed similarly. This confirms that the results of Eviatar and Ibrahim (2007) were not due to biliteracy but, most likely, morphological complexity.

According to the data, it was concluded that acquiring a different script may require more effort; however it does not yield any significant cognitive effects in executive control, mental rotation, or distinguishing morphological markers. Perhaps this is because similar scripts have their own challenges as participants actively inhibit one while reading the other. For example, Maltese/English bilinguals constantly inhibit English while reading Maltese, since English also utilises the Latin script. A better explanation, however, is that participants were tested at the height of their cognitive function abilities and perhaps testing participants of different age groups would yield different results. Previous research has shown bilingual groups composed of children or elderly participants were more likely to show bilingual effects than the age group used in this thesis (Donnelly, 2016).

Linguistic diversity was found to have a significant effect on the data. Although linguistic diversity showed no significant effects on inhibition and switching in the first study, the Arabic groups significantly outperformed all other groups on the mental rotation tasks in the second study, regardless of language proficiency and bilingualism. The third study also showed that there is no hemispheric preference when distinguishing morphological markers in both Maltese and in Arabic; although in English, all three English-speaking groups showed a left hemispheric preference when hearing the words. The results, therefore, show that while biliteracy effects were not found, languages exhibit unique characteristics that may influence results in bilingual effects research. As mentioned in Chapter 3, the results of previous studies on bilingual effects on executive control could have been exaggerated because the groups were not compared to monolinguals of both languages. Therefore Arabic's effect on mental rotation, could have been mistakenly attributed to bilingual effects. However, the mental rotation effects could result from the specific challenges of Arabic's complex script.

This thesis advantageously compared not only bilingual groups but also monolinguals. The comparison between the monolingual groups showed a significant difference between both the English and Arabic monolinguals on mental rotation and in distinguishing morphological markers, regardless of bilingualism. The research also showed that while linguistic diversity effects in bilinguals were apparent outside of the language domain (for example in mental rotation), pertaining to linguistic tasks, the effects were non-transferable to the other language (for example, distinguishing morphological markers in English compared to Maltese or Arabic). This lends to the view that linguistic diversity should always be considered; and more research is needed comparing different languages.

5.2 Limitations and Future Direction

The three studies lead us to conclude that further research would benefit greatly on comparing bilinguals to monolinguals of both language groups and not just English monolinguals. The data comparing bilinguals to monolinguals of both language groups will contribute to bilingual research, and language research as a whole. Perceiving English and other popular research languages as representing all languages may lead to errors in conclusions that could greatly, and negatively, influence future research. A meta-analysis of previous bilingual effects research, focusing on the languages tested, and the monolingual groups used, would indicate what bilingual effects are apparent and which unique language effects have been mistakenly attributed to bilingual effects.

Further research would also benefit from testing groups in early or later stages of life, given the exclusive focus of university-aged participants in this study. Visuospatial studies using different tasks would also beneficially indicate if results found in Arabic speakers are unique to the 360-degree angle of the Corsi blocks, or could be found using other.visuospatial tasks. Studies should also compare the performance of different languages on the tasks to examine which, if any, languages show similar patterns to those found in the Arabic speakers.

In Chapter 2, analysis was done comparing monolinguals with monolingual parents, to monolinguals with bilingual parents. Although the background collected on the participants does not provide enough to control for all variables, differences were found. The results revealed that the monolinguals with bilingual parents outperformed the monolinguals with monolingual parents on the ETD. Further research would benefit from controlling for influencing variables and would be able to show whether language's cognitive effects are hereditary

Research on complex morphology in Semitic languages would benefit from further comparisons with the use of varying cognitive analysis tools. Precise analysis and further comparisons between different language combinations may help distinguish what morphological attributes lead to hemispheric differences between languages. Morphological complex languages with no root words when compared to Arabic or Maltese will show if root words truly influence hemispheric variance between languages.

5.3 Conclusion

This thesis examined whether unique bilingual characteristics, specifically biliteracy, led to different results on cognitive functions tasks. Using three studies, this research first looked at the effects of biliteracy on executive control, specifically inhibition and switching, in both lifelong and late bilinguals. No bilingual or biliteracy effects were found on inhibition or switching, as all the groups performed similarly. The second study compared the groups on a mental rotation task and found that linguistic diversity showed a significant difference in the results. The Arabic speakers outperformed all other groups on mental rotation, regardless of language proficiency and bilingualism. The final study reiterated the importance of linguistic diversity since all three English-speaking groups showed a left hemispheric preference when hearing morphologically complex words, a preference that was not found in Maltese or Arabic. Overall, this research will positively contribute to current and future research as it uniquely compared rarely researched language groups while focusing on the key difference between Maltese and Arabic, namely biliteracy.

Appendices

A.1 Language Questionnaire

Email: **[ ] Check here if you DO NOT want to be contacted again.**	Participant ID
PART I: GENERAL DEMOGRAPHIC INFORMATION	
Age………………………………………………….. Sex …………………………………. Handedness….. Right / Left Profession/Subject studied... Current level of study or highest level achieved……………………………………………………………. At what age did you start school? At .... yrs old Have you lived in other places in which other languages are spoken?... If so, where and for how long?... Place of birth:...	
PART II: LANGUAGES SPOKEN	
1	
2	
3	
4	
5	
PART III: PARENTS' MOTHER TONGUES:	
What is your father's mother tongue? Does your father speak any other languages? Please specify	
What is your mother's mother tongue? Does your mother speak any other languages? Please specify	
If you have a child, which is their first language? Does your child speak any other languages? Please specify	

LANGUAGE 1						
LANGUAGE HISTORY – ACQUISITION OF LANGUAGE						
1. First contact with the language: since birth/at ___ yrs of age						
2. Choose the most appropriate option: - I hear the language spoken but I don't speak it ☐ - I both hear and speak the language ☐						
3. If you were schooled in this language, at what age did you learn to write it? ____ yrs old						
4. Environment in which you used the language in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**
Family						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
Official						
Schooling						
Teachers						
Classmates						
Immediate Environment						
Friends						
Neighbours						
LANGUAGE USE						
1. Do you continue to use the language? Yes ☐ No ☐ (If no, when did you stop using it? ___ yrs old)						
If yes, how often do you use it in each one of the following contexts (choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**
Family						
Partner						
Siblings/Nephews/Nieces						
Children						
Other relatives						
Official						
Colleagues						
Shopping						
Radio/TV						
Books/magazines						
Immediate environment						
Friends						
Neighbours						
Church/society						

Do you use different languages with the same person?						
COMMAND OF THE LANGUAGE						
Evaluate your command of the language in each of the following categories:						
		Basic	Weak	Moderate	Advanced	Fluent
Expression						
Comprehension						
Reading						
Writing						

LANGUAGE 2						
LANGUAGE HISTORY – ACQUISITION OF LANGUAGE						
1. First contact with the language: since birth/at ___ yrs of age						
2. Choose the most appropriate option: - I hear the language spoken but I don't speak it ☐ - I both hear and speak the language ☐						
3. If you were schooled in this language, at what age did you learn to write it? ____ yrs old						
4. Environment in which you used the language in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**
Family						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
Official						
Schooling						
Teachers						
Classmates						
Immediate Environment						
Friends						
Neighbours						
LANGUAGE USE						
1. Do you continue to use the language? Yes ☐ No ☐ (If no, when did you stop using it? ___ yrs old)						
If yes, how often do you use it in each one of the following contexts (choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**
Family						
Partner						
Siblings/Nephews/Nieces						

Children						
Other relatives						
Official						
Colleagues						
Shopping						
Radio/TV						
Books/magazines						
Immediate environment						
Friends						
Neighbours						
Church/society						
Do you use different languages with the same person?						
COMMAND OF THE LANGUAGE						
Evaluate your command of the language in each of the following categories:						

	Basic	Weak	Moderate	Advanced	Fluent
Expression					
Comprehension					
Reading					
Writing					

LANGUAGE 3

LANGUAGE HISTORY – ACQUISITION OF LANGUAGE

1. First contact with the language: since birth/at ___ yrs of age

2. Choose the most appropriate option: - I hear the language spoken but I don't speak it □
   - I both hear and speak the language □

3. If you were schooled in this language, at what age did you learn to write it? ____ yrs old

4. Environment in which you used the language in childhood: Frequency of use (choose one):

	Always	Often	Sometimes	Rarely	Never	Not applicable
Family						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
Official						
Schooling						
Teachers						
Classmates						

Immediate Environment						
Friends						
Neighbours						
LANGUAGE USE						
1. Do you continue to use the language? Yes ☐ No ☐ (If no, when did you stop using it? ___ yrs old)						
If yes, how often do you use it in each one of the following contexts (choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**
Family						
Partner						
Siblings/Nephews/Nieces						
Children						
Other relatives						
Official						
Colleagues						
Shopping						
Radio/TV						
Books/magazines						
Immediate environment						
Friends						
Neighbours						
Church/society						
Do you use different languages with the same person?						
COMMAND OF THE LANGUAGE						
Evaluate your command of the language in each of the following categories:						

	Basic	**Weak**	**Moderate**	**Advanced**	**Fluent**
Expression					
Comprehension					
Reading					
Writing					

LANGUAGE 4
LANGUAGE HISTORY – ACQUISITION OF LANGUAGE
1. First contact with the language: since birth/at ___ yrs of age
2. Choose the most appropriate option: - I hear the language spoken but I don't speak it ☐ - I both hear and speak the language ☐
3. If you were schooled in this language, at what age did you learn to write it? ____ yrs old
4. Environment in which you used the language in childhood: Frequency of use (choose one):

	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**

Family						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
Official						
Schooling						
Teachers						
Classmates						
Immediate Environment						
Friends						
Neighbours						

LANGUAGE USE

1. Do you continue to use the language? Yes ☐ No ☐ (If no, when did you stop using it? ___ yrs old)

If yes, how often do you use it in each one of the following contexts (choose one)

	Always	Often	Sometimes	Rarely	Never	Not applicable
Family						
Partner						
Siblings/Nephews/Nieces						
Children						
Other relatives						
Official						
Colleagues						
Shopping						
Radio/TV						
Books/magazines						
Immediate environment						
Friends						
Neighbours						
Church/society						
Do you use different languages with the same person?						

COMMAND OF THE LANGUAGE

Evaluate your command of the language in each of the following categories:

	Basic	Weak	Moderate	Advanced	Fluent
Expression					
Comprehension					
Reading					
Writing					

LANGUAGE 5						
LANGUAGE HISTORY – ACQUISITION OF LANGUAGE						
1. First contact with the language: since birth/at ___ yrs of age						
2. Choose the most appropriate option: - I hear the language spoken but I don't speak it ☐ - I both hear and speak the language ☐						
3. If you were schooled in this language, at what age did you learn to write it? ____ yrs old						
4. Environment in which you used the language in childhood: Frequency of use (choose one):						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**
Family						
Mother						
Father						
Grandparents						
Siblings						
Other relatives						
Official						
Schooling						
Teachers						
Classmates						
Immediate Environment						
Friends						
Neighbours						
LANGUAGE USE						
1. Do you continue to use the language? Yes ☐ No ☐ (If no, when did you stop using it? ___ yrs old)						
If yes, how often do you use it in each one of the following contexts (choose one)						
	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Not applicable**
Family						
Partner						
Siblings/Nephews/Nieces						
Children						
Other relatives						
Official						
Colleagues						
Shopping						
Radio/TV						
Books/magazines						
Immediate environment						
Friends						
Neighbours						
Church/society						

Do you use different languages with the same person?						
COMMAND OF THE LANGUAGE						
Evaluate your command of the language in each of the following categories:						
		Basic	**Weak**	**Moderate**	**Advanced**	**Fluent**
Expression						
Comprehension						
Reading						
Writing						

PART IV: MOTIVATION (Arabic Language Learners Only)
1. Why did you decide to study Arabic?
2. Are you planning on continuing to study Arabic? Yes / No
3. Why are you planning on continuing/ not continuing?
4. What is the most difficult aspect of learning Arabic?
5. How many hours a week do you spend/plan on spending studying Arabic outside of class?
6. Are you planning on visiting an Arabic speaking country? Yes / No
7. When and for how long are you planning to visit?
8. What do you hope to gain from your visit?

A.2 Socioeconomic Status (SES) Questionnaire

Educational Background

1. Father’s Job ______________________
2. Mother’s Job ______________________

3. Highest Level of Education:

	No Formal Schooling	Highschool Diploma	Associate Degree	Bachelor's degree	Master's Degree	PhD
Father						
Mother						

4. Household Income depending on National Average (With 1 being the Lowest and 10 being Highest)

1	2	3	4	5	6	7	8	9	10

5. Was the school you attended Private / Public?

6. How often were you able to have access to computers and other educational materials after school?

Never	Rarely	Sometimes	Often	Always

A.3 Words for the Lexical Decision Task (Chapter 4)

English Words and Non-Words

Complex Words

Owner	Living	Hatred	Verbal
Sadly	Ending	Unfair	Ironic
Lucky	Safety	Recall	Insane
Usage	Leader	Search	Inside
Singer	Worker	Refund	Driver
Dancer	Wooden	Useful	Golden

Simple Words

Mouse	Rabbit	Screen	Dress
Image	Window	Forest	Apple
Issue	League	Lesson	Beard
Engine	Sponge	Ocean	Razor
Advice	Violin	Wealth	Laugh

Complex Non-words

Baral	Arting	Inbear	Reday
Fitry	Dogist	Intame	Vater
Sunly	Ballic	Inchor	Landy
Gapty	Hornal	Reton	Poomy
Maltor	Hatage	Armen	Inspy

Simple Non-words

Abent	Idace	Dittle	Gealth
Leard	Ukint	Adeast	Avort
Farble	Benslo	Udoryp	Bemin
Icrog	Wanget	Iglipe	Lainth
Oplep	Donkle	Hamage	umtado

Maltese Words and Non-Words

Complex Words

Proprjetarju (Owner)	Tidħaq (she laughs)	Tiekol (Eating)	Kelliema (speakers)
Sfortunatament (Unfortunetly)	Zeffiena (dancers)	Dehbiena (Golden)	Bahrija (from the sea)
Nifhemek (I understand you)	Għajxien (Living)	Xemxija (Sunny)	Gnejna (small garden)
Thallinix (don't leave me)	Marret (She went)	Ktibna (We wrote)	
	Kittieb (Writer)	Ambjentali (environmental)	
	Sewwieq (Driver)	Literallment (literally)	
	Għalliema (Teacher)		

Simple Words

Gobon (Cheese)	Widna (Ear)	Xibka (Net)	Libsa (Dress)
Halib (Milk)	Ghajn (Eye)	Ragel (Man)	Daqna (Beard)
Tuffieh (Apples)	Sigra (Tree)	Lejl (Night)	Ktieb (Book)
Laham (Meat)	Werqa (Leaf)	Bahar (Sea)	Baqra (Cows)
Hobz (Bread)	Karta (Paper)	Ghana (Wealth)	Qmis (Shirt)

Complex Non-words

Baralment	Artin	Ilbear	Dajiet
Fitret	Iddog	Ittamiel	Vatersiet
Sunlek	Ballicsiet.	Chorijiet	Ilandaj
Gaptxien	Horniel	Irreton	Pomis
Maltieb	Hatagiet	Armien	Innapaj

Simple Non-words

Dittel	Agrawa	Brega	Tanjat
Nobog	Smig	Kanjr	Mgorn
Harb	Hflara	Harib	Klak
Marna	Mgana	Kamasa	Humera
Nagna	Lahra	Morot	Trena

Arabic Words and Non-Words

Complex Words

تعليمي (study)	مكسور (broken)	مكافحة (resistance)	طيارة (plane)	اسطوره (legend)
اختبار (test)	استمرار (continuance)	استعداد (readiness)	اخبار (news)	مفتاح (key)
مدرسة (school)	امتحان (examination)	تعبير (expression)	اجتماع (meeting)	مزرعة (farm)
تفكير (thinking)	مسطرة (ruler)	مرتبة (position)	مكتبة (library)	متجمد (frozen)
مقبرة (cemetery)			تنظيم (arrange)	خزان (cupboard)
معركة (battle)				

Simple Words

بهلوان (tumblr)	حقيبة (bag)	خنزير (pig)	مروحة (fan)
طاولة (table)	زعفران (saffron)	امعاء (intestine)	عائلة (family)
سكرتيرر (secretary)	تلفاز (television)	صنارة (fishhook)	زاوية (angle)
تيلفون (telephone)	نموذج (sample)	زرافة (giraffe)	كهرباء (electricity)
عصفور (bird)	عامود (pillar)	مهرجان (festival)	

Complex Non-words

تنخيب /tɑnxɪb/	استعراد /æstʕrɑ:d/	مقطرة /mqtˤrɑ:/	مزكبة /mzkæbɑ:/
شكعدان /ʃkʕdɑn/	استهران /æsthrɑ:n/	مهاري /mhæri:/	مكراث /mkraθ/
احباز /əħbæz/	اخباج /əxbʌdʒ/	محبقة /mħbqɑ:/	ملتاح /mltæħ/
دناعة /dnæʕɑ:/	خزادة /xzɑ:dɑ:/	محشدة /mħʃdɑ:/	موقشة /moʊqʃɑ:/
اشحوره /æʃħoʊrɑ:/	مدرعة /mdrʕɑ:/	مخدسة /mxdæsɑ:/	رافلة /rɑ:flɑ:/

Simple Non-words

زعكراج /zʕkrædʒ/	بائلة /bæi:lɑ:/	كنزير /knzi:r/	مرموان /mrmæwæn/
تيلبوع /telbaʊʕ/	بناره /bnærɑ:/	كرافة /kræfɑ:/	مصبلة /msbælɑ:/
سموذج /smoʊðdʒ/	طهبوان /tˤ hbaʊn/	كرنيت /krni:t/	مصطحة /mstˤħɑ:/
سكرفتير /skrfti:r	هصبور /hsbaʊr/	كرعول /krʕoʊl/	دناره /dnærɑ:/
امعال /æmʕæl/	كعيسة /kʕæsɑ:/	كرسباء /krsʌbɑ:/	مزوشة /mzwæʃɑ:/

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